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Optimum Conjunctive Use of a Dual-Purpose Desalting Plant and Multi-Purpose Surface Water Reservoirs

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FOREWORD

This is one of a continuing series of reports designed to present accounts of progress in saline water conversion and the economics of its application. Such data are expected to contribute to the long-range development of economical processes applicable to low-cost demineralization of sea and other saline water.

Except for minor editing, the data herein are as contained in a report submitted by the contractor. The data and conclusions given in the report are essentially those of the contractor and are not necessarily endorsed by the Department of the Interior.

ACKNOWLEDGEMENTS

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Without the help from these individuals the accomplishment of our objectives would have been impossible.

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ABSTRACT

The objective of this study was the development of an analytical technique to assess the economic benefits to be derived from the conjunctive operation of a dual purpose desalting plant with multipurpose surface water reservoirs.

To accomplish the above objective the following tasks were performed:

1. Mathematical models were developed to determine the optimum long term operation parameters for a system comprising a dual purpose desalting plant and several existing multipurpose surface water reservoirs. The optimization models use simulation and incremental dynamic programming techniques. These models are developed for two different reservoir system configurations, i.e., reservoirs built on the same river, and reservoirs on branching rivers.

2. Computer programs using FORTRAN language were developed to solve the mathematical models developed in task 1. The logic of the programs involved the read-in of input data, selection of a desalting capacity and calculation of firm water and electricity contract levels. A production possibility curve showing the tradeoff between firm water and firm electricity output levels was then developed for each specified level of desalting capacity.

3. An economic model was developed to calculate the benefit and cost from the conjunctive use of surface reservoirs and desalting plants based on output data from the computer programs. An incremental firm water supply curve was then developed, based on these benefits and cost calculations.

4. The models developed were applied to determine the optimum long term operation mode of a hypothetical conjunctive system.

CONCLUSIONS

A number of conjunctive system configurations have been investigated in this study to demonstrate the feasibility of using dual purpose desalting plants conjunctively with existing systems of surface water supply. Results from this study for the hypothetical but realistic cases investigated showed: On the average, the cost--for new increments of water supplied from conjunctive operation of dual purpose desalting plants and existing reservoirs--may be as much as 55% lower than that for the case in which the desalting plant is operated as a base load plant.

The use of the methodogy developed in this study can be made for planning purposes, to determine the size of the dual purpose desalting plant required, the load factor, the unit cost of water from conjunctive operation, and the firm and dump energy production, for a specified increment in firm water supply.

A summary comparison of the unit costs of water from different system configurations are given in the table below.

Unit Cost of Water $1 acre-foot

Additional firm water supply (100 acre-foot)	Desalting Plant (Case A2)	Conjunctive Use: Desalting plant with a regulating reservoir (Case A3)	Conjunctive Use: Desalting plant with four reservoirs (Case A4)	Per cent Reduction in unit cost: Case A4 over A2	Per cent Reduction in unit cost: Case A4 over A3
100	129	113	56	56%	50%
150	132	111	54	59%	51%
200	132	110	54	59%	52%
250	132	108	70	47%	35%

GLOSSARY OF TERMS

Terms Used In Text

Critical Period:

In a long-term historical hydrologic record, the best output levels of firm water and firm energy is controlled by a sequence of subnormal flows over a consecutive period of the record. This is the critical period, and in analysis always begins with the reservoir full and always ends with the reservoir at its lowest permissible level.

Deterministic:

A quantity with fixed non-probabilistic characteristics.

Dump energy production:

Energy production over the base load production levels. This is a variable quantity, and is affected by seasonal variations.

Firm energy production:

The uninterruptible firm energy production which can be contracted for sale during the entire period of analysis.

Inflows:

The result of runoff from precipitation. When, in a drought, the volume of runoff is low, it is referred to as "more critical," and when the volume of runoff is high, the inflow conditions are "less critical."

Safe yield:

The maxiumum rate of sustained flow that a water system can provide, in the time period being considered for analysis.

Stochastic:

A quantity with random or probabilistic characteristics.

Symbols Used In Text

a	=	Conversion factor from millions of gallons to 103 acre-feet.
A_n	=	Surface area of reservoir.
ACOST	=	Annual cost
ADE	=	Annual dump energy production.
ADW	=	Annual dump water production.
AF	=	Acre-feet.
AFC	=	Annual fixed cost of desalting plant
AFE	=	Annual firm energy production.
AFW	=	Annual firm water production
ALPTC	=	Annual low pressure turbine cost.
AOMC	=	Annual operation and maintenance costs
ARCOST	=	Annual reservoir cost
ASC	=	Annual steam cost for desalting plant
β_n	=	Fraction of water demands in month n.
C	=	When used as a subscript, refers to 'conjunctive' system operation
CAPDES	=	Capacity of desalting plant in million gallons per day.
CR	=	Capital recovery factor
D	=	When used as a subscript, refers to desalting plant operation
DE	=	Dump energy
DEP	=	Unit dump energy sale price
DY	=	Number of days in one year
Δ	=	Net change in the quantity
ER_n	=	Evaporation rate in month n, ft/unit area
EVADE	=	Equivalent uniform annual dump energy production

EV_n	=	Total monthly evaporation from reservoir
F	=	Desalting plant unit costs in ¢/1000 gallons
FE	=	Firm energy
FEP	=	Unit firm energy sale price
i	=	Interest rate
I_j	=	(j-th) Water inflow into the system
KA	=	Kilo acres (1000 acres)
KAF	=	Kilo acre-feet (1000 acre-feet)
LF	=	Operating plant load factor
LPTG	=	Low pressure turbine generator
MGD	=	Million gallons per day
MW	=	Megawatts
MWH	=	Megawatt hours
n	=	Number of years, for capital recovery costs
P_j	=	(j-th) water demand in the system
R	=	When used as a subscript, refers to "Reservoir" operation
REV	=	Revenue from sale of energy
R_n	=	Total water requirements in month n, of reservoir operation (evaporation and external demands)
$S_{E,n}$	=	Ending storage level of reservoir in period n
$S_{I,n}$	=	Initial storage level of reservoir in period n
UNCOST	=	Unit cost of water production

CHAPTER 1

INTRODUCTION

The question of conjunctive use of dual purpose desalting plants and existing surface water reservoirs is of particular interest because of the special economics of water and power generation. Water and hydroelectricity generation from surface reservoirs are subject to natural fluctuations due to seasonal and annual random changes in stream flows. But to receive a high price for water and hydroelectricity from reservoirs, these outputs have to be dependable. So the most adverse hydrologic conditions will usually determine the level of dependable water and energy productions. In fact, in most surface reservoir systems a large amount of water and energy produced either cannot be sold or has to be sold at lower dump prices, since water and energy outputs during wet years will exceed the contract level for firm dependable water and energy.

The firm yield can be increased by installation of additional reservoirs to store the water in wet periods, to be used up in drought periods. However, the development of new surface reservoirs is becoming increasingly expensive and difficult. Large scale surface systems may cause inundation of valleys and use of land areas which have historic or aesthetic value, which has caused a growing concern and opposition about the ecological consequences of such developments. Nevertheless, there is continued growth of critical water needs, and new means have to be considered. Desalting water from the seas or from brackish supplies, using expected new sources of inexpensive energy, used conjunctively with existing systems, hold promise to meet the requirements.

The ability of a desalting plant to supply fresh water during the critical period of hydrology might therefore play a particularly important role in future water resources planning. It is true that the unit cost of desalting water is rather high in comparison with that from conventional sources. But the mere possibility of producing the desalted water to fill firm water contracts during drought periods of surface water supply means that, in a conjunctive system, the firm water and energy supply from conventional sources can be raised for the entire planning period. Water and hydroelectricity that would otherwise have to be sold at low prices can be safely committed at firm contract prices if the dual purpose power and desalting plant is available as a standby capacity to supply supplemental water during a drought period.

The picture, then, is of a desalting plant, either nuclear or fossil-fueled, operated at some point economically close to a source of saline or brackish water. This plant will be operated as a component of a system, rather than a separate entity. The other components of the system will be a group of surface reservoirs. The system will supply water for irrigation and/or municipal use at various specified outflow points. The reservoir subsystem, by itself, would ordinarily be operated in such a way as to maximize the total income from supplying contracted firm water and contracted firm energy, plus any income from dump energy and water.

In periods of drought, energy generation in the reservoir subsystem would tend to be restricted by needs for water above the generation point. By adding a desalting and power generation plant, additional power or water could be supplied to the system. The general tendency, given the contract basis of water resources planning, would be then to supply water for irrigation, for example, from the stream flow or reservoir storage during periods of high flow, while the desalting power generation plant would be used to produce energy instead of water. In periods of low flow, on the other hand, the plant would tend to be converted to a desalting operation in order to meet the guarantees of water supply made to users. The details of the operation would be arranged so as to again maximize income from the sale of both water and power.

A study carried out by the Northeast Desalting Team of the U. S. has introduced the concept of "drought proofing" large areas by desalting plants.[1] However, the specific design and operation of a conjunctive system is rather complicated. The optimum design and operation of such a system depends on: (a) the detailed characteristics of the surface water hydrology of the region in which the reservoirs are located (particularly the streamflow magnitude during drought periods when the desalting plant would be expected to make maximum contributions to the conjunctive system); (b) the storage capacity, power plant capacity, and other physical characteristics of the existing multipurpose surface water reservoirs; (c) the demand for firm water and electrical energy; and (d) alternatives to meet firm water and electrical energy demands.

Computer Programming Approach

The computational difficulties of optimum design and operation of a conjunctive system are, in general, great. Nevertheless, with the aid of modern optimization techniques and high speed computers, the problem can be reduced to tractable terms. The Water Research Association in the United Kingdom has been interested in the application of optimization techniques to study the possibilities of desalting as a supplement to conventional water supply. Burley and Mawer of WRA have reported on several occasions about their use of simulation techniques in mathematical optimization studies of a conjunctive system which included a single purpose reservoir and a dual purpose desalting plant.[2] to [6] Clyde and Blood have also used simulation to find optimum operation of a single purpose desalting plant and a single purpose water supply reservoir.[7][8]

Simulation technique performs fairly satisfactorily when the number of decision variables are few. However, the number of decision variables in an operation problem equals at least the number of decision periods, and the number of alternative sequential decisions increases very rapidly with number of periods. To remedy this problem, operating rules are predetermined in accordance with some conventional methods when simulation is used in the analysis of conjunctive desalting and surface water reservoir systems. There is, however, no assurance that optimum operational rules will be reached. On the other hand, when mathematical programming techniques such as linear or dynamic programming are used, then there is a theoretical assurance that the optimal solution will be reached given enough computational time. Both linear and dynamic programming techniques have been used in modeling of conventional water resources systems.[9][10][11] These two techniques are well-suited for optimization of problems when a limited amount of resource has to be allocated among different uses and time periods.

In a multipurpose surface reservoir, energy production is a function of both water release and the level of storage. The energy production function is, therefore, a nonlinear function of these two variables. When linear programming is used to optimize reservoir operation, the assumption has to be made that reservoir storage level is constant and energy production is a linear function of reservoir release only. This is not realistic in most large scale projects. Reservoir storage level changes due to flood control, mandatory release and other requirements. Dynamic programming has, on the other hand, the advantage that nonlinearities can be taken into account in the formulation of the mathematical models without much difficulty.[12]

A dynamic programming model was developed by Mobasheri and Harboe to determine the optimum longterm operating policy of a single multipurpose surface reservoir which is operated in conjunction with a dual purpose desalting plant.[13] The purpose of the conjunctive system included production of firm water supply, firm on-peak and dump energy supply, and flood and water quality control downstream from the surface reservoir. The economic objective was the maximization of the present worth of net benefits from constructing and operating a desalting plant with an existing multipurpose reservoir. This benefit was a function of annual firm contract levels for water supply and on-peak energy, annual dump energy production, relative prices for these outputs, and the cost of constructing and operating the dual purpose desalting plant. For the case studies the water cost for new incremental supply was reduced by about 38% when conjunctive operation was carried out.

There is no question that dynamic programming is an efficient optimization tool for finding optimum operation for systems with a large number of decision periods. There are however, two main drawbacks with the use of dynamic programming. First, there is no general dynamic programming algorithm available. This means the analyst has to develop his own mathematical model based on Bellman's Principle of Optimality, which establishes a general mode of procedure for many optimization problems.(14) This principle simply states that

> "an optimal sequence of decisions in a multi-stage decision process problem has the property that whatever the initial stage, state, and decision are, the remaining decisions must constitute an optimal sequence of decisions for the remaining problem, with the stage and state resulting from the first decision considered as initial conditions in the on-stage problem."(15)

An equation which represents the functional relation between two stages of the planning period is then developed. Based on this recursion equation and the set of equations describing the constraints on operation a computer program then has to be written and debugged. Of course, to analyze systems with the same physical configuration there will be no need for further programming effort. Unfortunately, there is always some variation in system configuration when different surface water resource systems are investigated.

For example, the number of reservoirs, the purposes of operation, the length of "critical period" of hydrology, and other physical parameters are different from one surface reservoir system to another one. Modification of the mathematical description of the system and computer program will, then, be necessary as a general rule, when considering new systems.

The second major drawback with the use of dynamic programming is the dimensionality problem. As the number of state variables (for example, the number of reservoirs) increases, the computation time increases exponentially. One way to remedy this problem will be the use of a multilevel optimization model such as the one developed by Hall and Shephard.(16) Another method is the use of an incremental dynamic programming algorithm.

This technique has been used successfully by Keckler and Larson for finding the optimum operation of water resource systems.[17]

Since the models to be developed in this investigation have at least two state variables and three decision variables per decision period, solution by conventional dynamic programming algorithms would require a large number of calculations, and thus unreasonable computational time. The incremental dynamic programming approach was, therefore, used as the main optimization tool in the study. This approach circumvents the difficulty with dimensionality by reducing the number of feasible states of the system that have to be analyzed at each particular time period. This also implies a reduction in the number of feasible combinations of decision variables.

Specifically, the algorithm starts with a feasible initial policy; i.e., a sequence of states through which the system must go in each time period, and then analyzes only new policies which are "close" to the initial policy. A "close" new policy means a policy that is no more than a fixed amount above or below the previous policy. In this way a better policy is determined; i.e., one that yields a higher value for the objective function. The procedure follows in an iterative way, replacing the initial policy by the new one determined in each successive iteration and solving the whole problem in each iteration. These iterations are repeated until convergence is obtained, i.e., no new policy can be found to yield a higher value for the objective function. This technique assumes that the n-dimensional operating surface has only a single global maximum point rather than local relative maximum points. However, by starting with several initial policies, this disadvantage can be overcome in practice.

In most cases, water and electricity requirements are determined by projecting past consumption, with adjustments to reflect the increase in per capita consumption because of increases in industrial and household income. To satisfy these increased requirements there is need for an additional "firm" supply of water and electricity in the future. The water resource planners are, therefore, interested in determining the additional "safe yield" from new water supply development projects. "Safe yield" is usually defined as the maximum rate of sustained flow that a water supply system can provide. (For elaboration, see reference 18.) Based on past historical runoff data and the use of mass balance equations the "safe yield" can be obtained for a given size of reservoir. Of course, the drought period of the runoff record will determine the "safe yield." This portion of the runoff record is usually called the critical period. It is defined as the period of time in which the historical hydrologic record would have been most critical with respect to the demands of the system.(18) In other words, for a given "safe yield" level, the critical period is the period in which the largest reservoir storage volume would have been required. This means that if the reservoir system will be able to meet the largest safe yield during the critical period of hydrology then the system will also be capable of meeting this target when the complete historical runoff record is used to analyze the operation of the system. Therefore, for the purpose of calculating firm water and energy supply from a water resource system it is only necessary that the critical period is determined from the historical hydrologic record. The model is not limited in use by the available recorded data; data quality will only affect the type of results obtained in this deterministic model.

Monthly data from this critical period are then used in calculations of the mass balance equation. However, to determine this critical period it becomes necessary to know the precise makeup of the water resource system, the operational purposes of the system, and the optimum operating policy that will be used. The investigation by Hall and his associates showed that the length of the critical period is usually less than ten years for most regions of the United States.(18)

In the models developed in the next chapters, a monthly deterministic hydrologic runoff record is used for determining the firm level of outputs from the water resources systems investigated. Furthermore, the length of the critical period was assumed to be ten years to be on the conservative side. This period is determined based on historical runoff record and mass balance equations for the reservoir system under investigation. At the beginning of the critical period, <u>i.e.</u>, start of operation, reservoirs are full. They then reach minimum storage level by the end of the critical period. Of course a number of equally likely hydrographs of the same length as the historical record can be generated.(18)(19) The critical periods from these synthetic records may be determined and used to study the snsitivity of the optimum firm supply levels of water and energy to the synthetic runoff values.

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CHAPTER 2

CONJUNCTIVE SYSTEM CONFIGURATION AND ANALYSIS

The water resource system studied is comprised of a dual purpose desalting plant and several linked multi-purpose surface water reservoirs. The benefit from the conjunctive operation of such a system is to be determined. This benefit is brought about by an increase in firm water and on-peak energy production when the operation of the reservoirs and the dual purpose desalting plant is integrated.

2.1 Dual Purpose Desalting Plant.

A simplified flow diagram for the dual purpose desalting plant, to be operated in conjunction with reservoirs, is shown in Figure 2.1. A heat source is available. This could be produced, in general, by a fossil or nuclear generating plant. (A nuclear heat source was selected here for study purposes.) The high pressure steam produced enters the turbogenerators. These turbogenerators produce electricity and low grade exhaust steam. The electricity is used for sale as base load electricity, for inplant use, and for water production. The low grade exhaust steam is used in the water plant. However, if the water plant is not operated at full capacity, then the unutilized portion of the low grade exhaust steam is diverted into low-pressure turbogenerators to produce on-peak or dump electricity. Only water production and electricity produced from the low-pressure turbogenerators are lumped with water and energy production from surface water reservoirs. The assumption is made that reservoirs are not operated to produce base load electricity. Therefore, for the base load electricity produced from the dual purpose desalting plant a separate contract may be formulated. By making this type of assumption the operation of the dual purpose desalting plant is separated into two separate parts. The part having an impact on the conjunctive operation with reservoirs is shown in Figure 2.2. This part of the system can be seen as a dual purpose desalting plant that purchases firm low grade exhaust steam and some electricity from outside. Depending upon the need for the quantity of the product water some portion of the low grade steam is used for the distillation process. The remaining exhaust steam is used for on-peak or dump energy production.

The water plant consists of several modules, each of which can be operated independently of the others.

2.2 Surface Reservoir System.

Surface water reservoirs are multipurpose. The main purposes are: flood control, firm water and electricity production. It is desirable to have the hydroelectricity

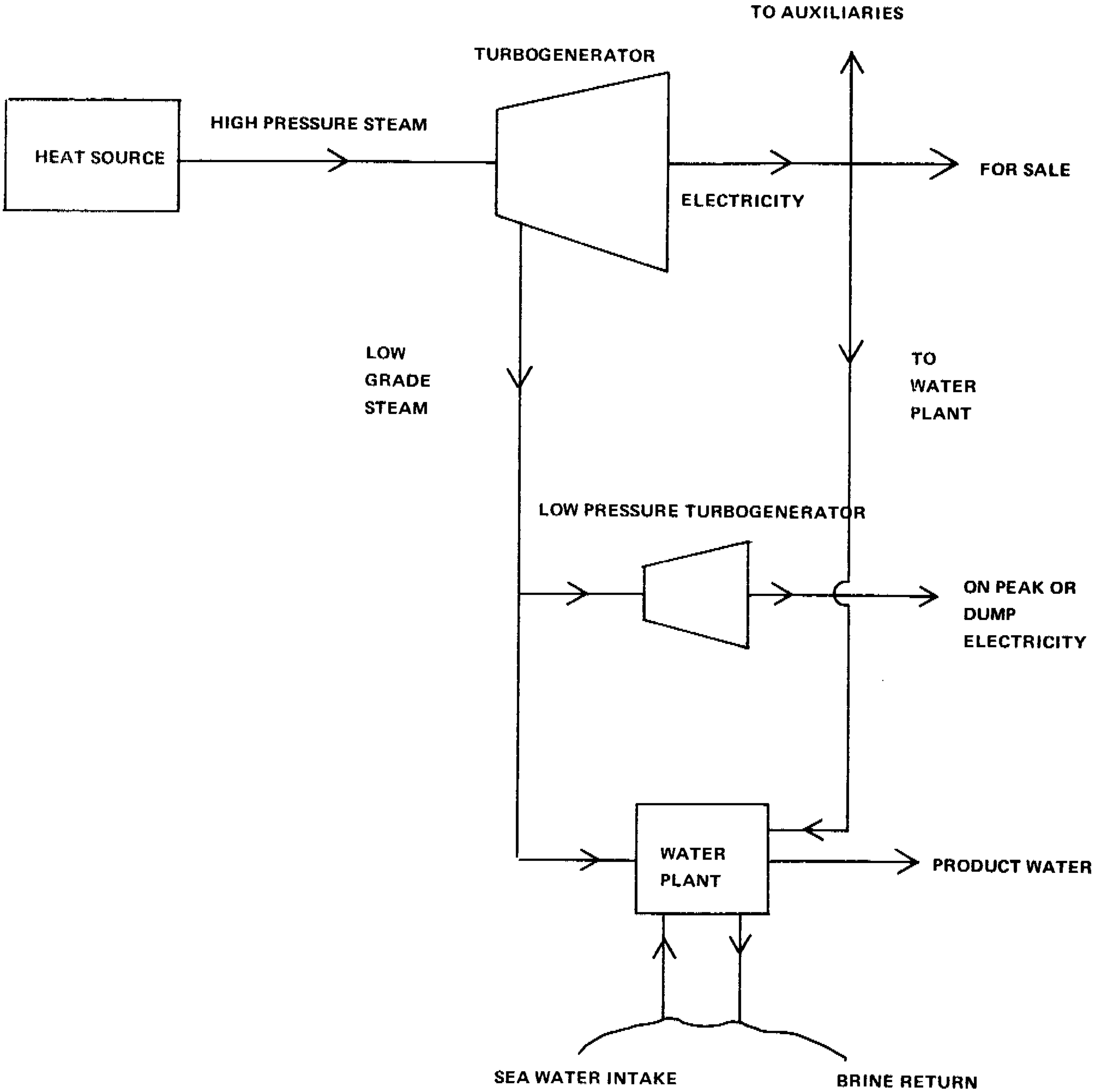


Figure 2.1 Simplified Flow Diagram for the Dual Purpose Desalting Plant

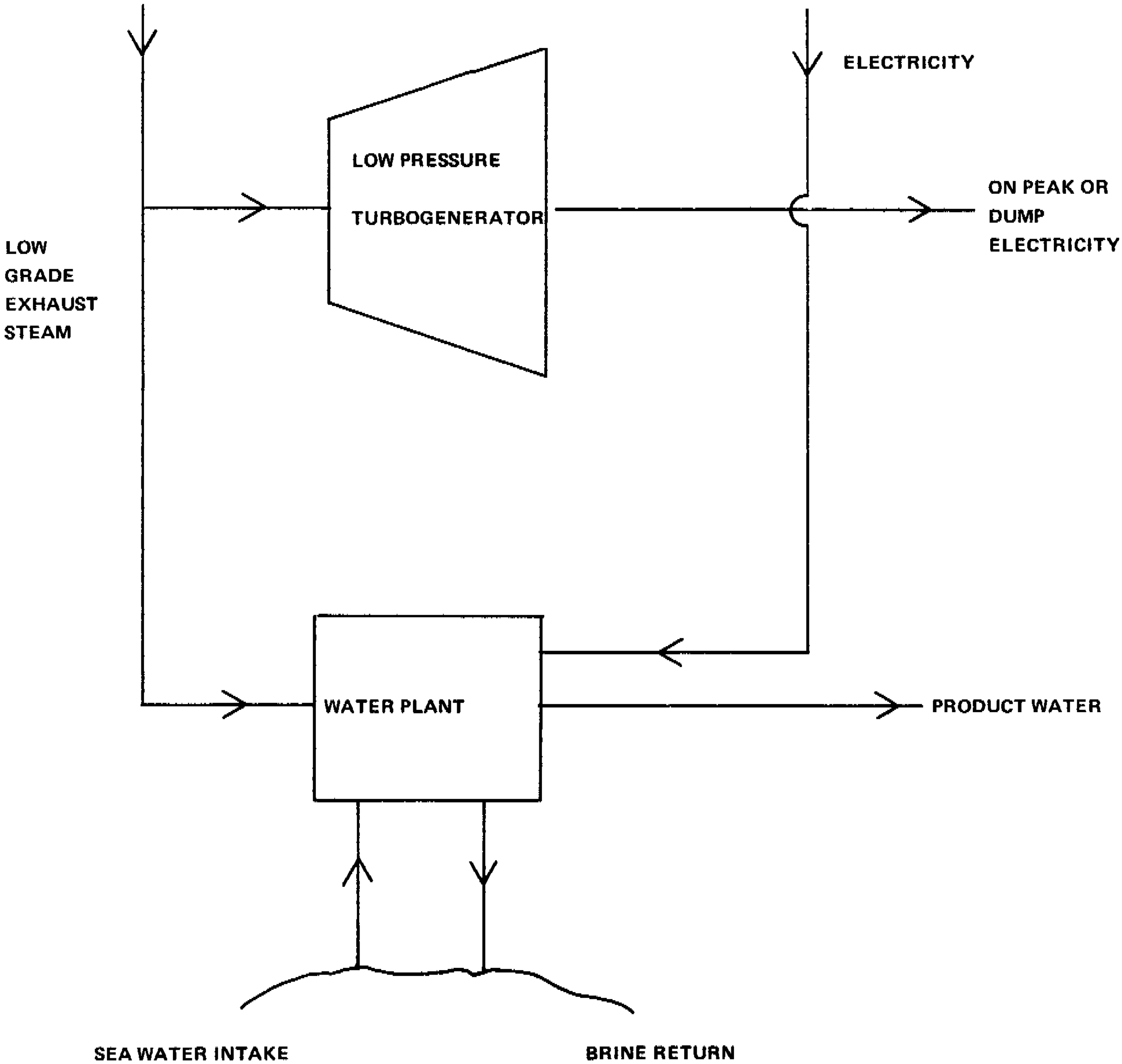


Figure 2.2 Simplified Flow Diagram for the Desalting Plant Isolated from the Total System

production during the peak hours. In addition, to get a high unit price, this on-peak electricity production must be on a firm level. Of course, due to limitations on storage and hydropower plant sizes and to large changes in river inflows, there will always be some dump energy production. Two basic reservir system configurations will be considered. The mathematical models and computer programs will be developed for these two general configurations.

A. Series Reservoirs.

For illustrative purposes, a number of reservoirs are assumed to be constructed on the same river, to fully utilize the power production and storage capacity of the system. Figure 2.3 shows such a system. With a system of four multipurpose reservoirs on a single main river, two of these reservoirs are assumed to be large storage reservoirs with variable head, the other two are smaller constant head reservoirs. Figure 2.3 also shows how this reservoir system is integrated with the desalting plant. There are several tributaries to the main river. Tributaries between two series reservoirs are lumped into one inflow. There are several water diversion points on the river. These water diversions are made to meet upstream irrigation and municipal demands. A large municipal industrial water demand, P_4 in Figure 2.3, is located near the sea. It is a portion of this demand that water from the desalting plant is going to supply. Regardless of the size of the desalting plant and the quantity of demand P_4, upstream water requirements, i.e., P_1, P_2 and P_3 must be satisfied. The annual firm level and monthly distribution of these upstream requirements act as constraints on water release policy from the reservoirs.

B. Parallel Reservoirs.

In the assumed reservoir system configuration there is one main river with two large branches. There are two reservoirs on each branch. The upstream reservoirs are larger and have variable water storage levels. The two downstream ones are constant head reservoirs. Figure 2.4 shows this parallel reservoir system configuration. Again, there are several smaller tributaries into the main stream and the two large river branches. There are four water diversion points. The one downstream is near the sea. A portion of the water demand in this zone is satisfied by the desalting plant. As for the series reservoirs case, the upstream water requirements act as contraints on water release policies from the reservoirs.

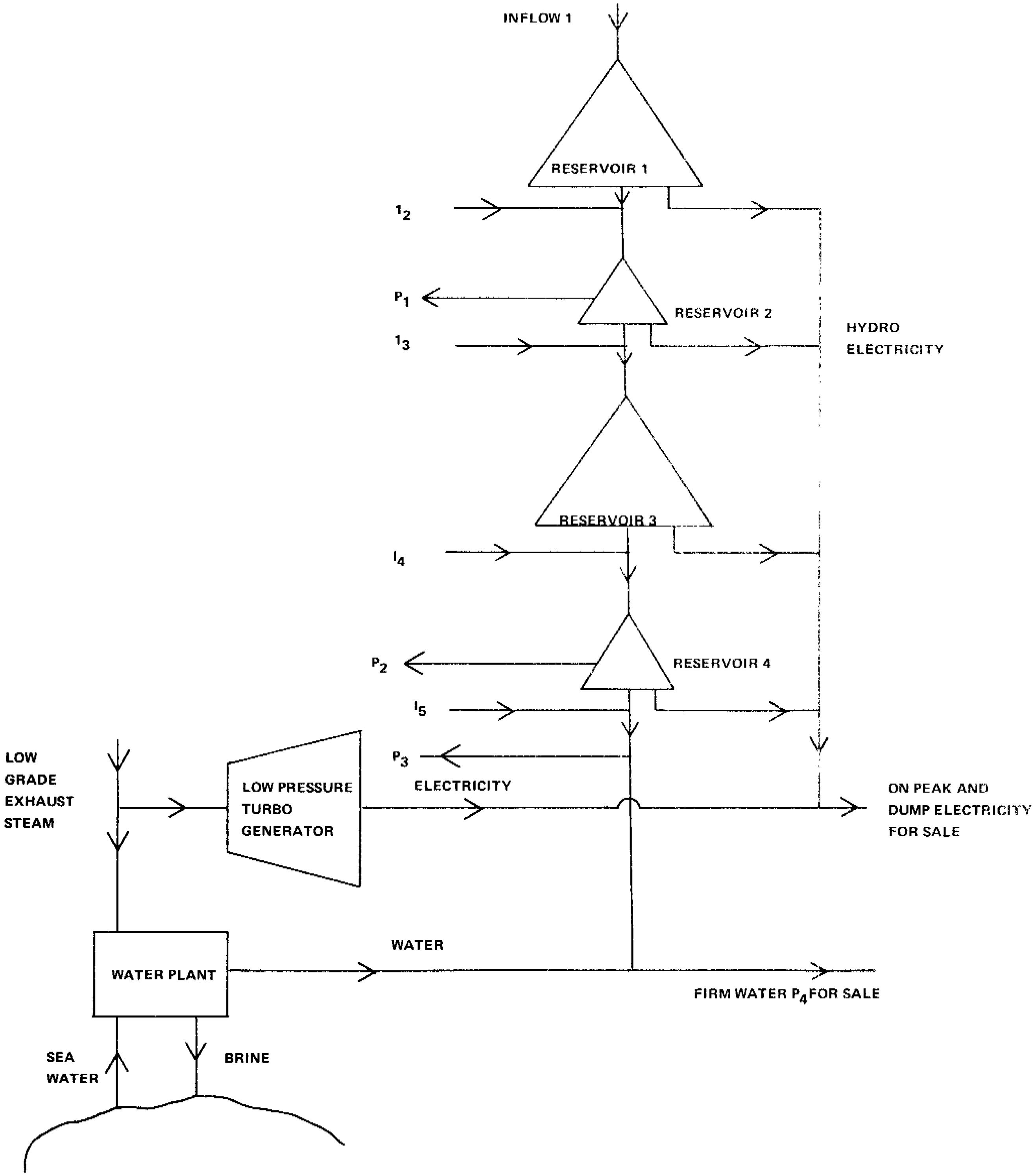


Figure 2.3 System Configuration for Series Reservoirs and Desalting Plant (I's are water inflows, P's are water demands.)

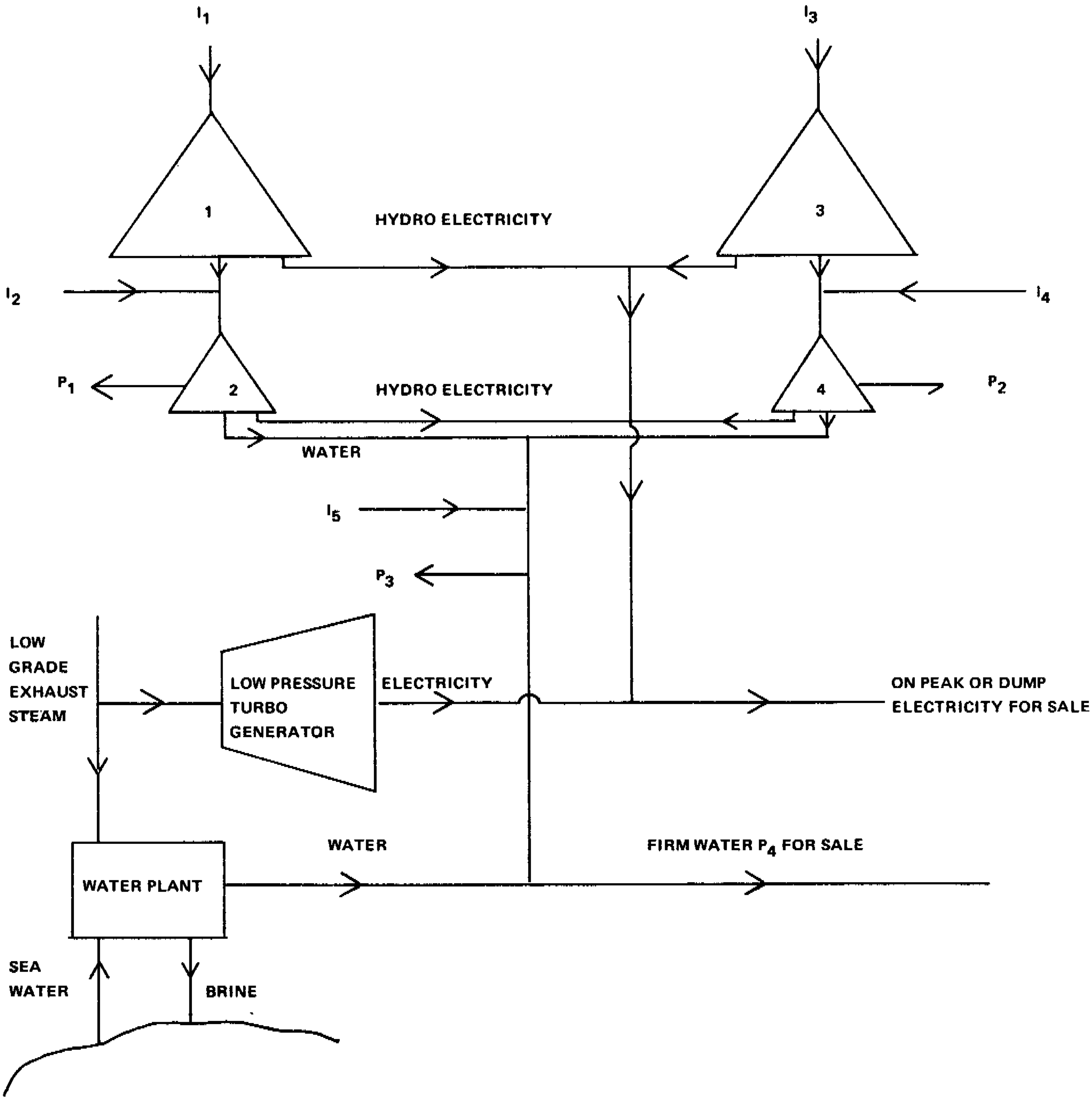


Figure 2.4 System Configuration for Parallel Reservoirs and Deslating Plant (I's are water inflows, P's are water demands.)

2.3 Mathematical Modeling of the Conjunctive Systems.

As it has been stated before, the main objective is the determination of the optimum incremental water supply cost when the water requirement in the zone near the coast, i.e., P_4 in Figure 2.3 and 2.4, is increased. To find this supply curve it is necessary to parameterize the problem with respect to the size of the dual purpose desalting plant. For a given desalting plant capacity the maximum safe yield for water from the conjunctive system may be calculated by means of a simulation model. However, to find the optimum combinaion of firm on-peak electricity production and firm water supply the tradeoff between these two outputs must be determined. The incremental dynamic programming model is used to calculate these tradeoffs by using the water supply as a parameter and finding the maximum feasibl firm on-peak energy that the system can produce. Furthermore, a forward simulation model is used to calculate the dump energy production level.

The details and formulation of these mathematical models are given in Appendix A. Figure 2.5 shows the master flow chart for these models.

The concept of the "critical period" is used in these models. This means an analysis is carried out to find the drought period of the river system. This analysis is based on historical runoff data. The runoff data, i.e., river flow record, for this critical period is then used as a deterministic input into the mathematical models.

All the calculations are carried out for discrete time intervals, i.e., one month intervals, over the critical period. A smaller time interval could have been used, but at the cost of increased computational effort. However, one month time intervals give sufficient accuracy for the problem at hand, i.e., a long term operating model for planning purposes.

During the critical period, when water level in the reservoir is going down, more reliance is placed on water from desalting plants. A greater percentage of the total requirements are satisfied from desalted water, and the plants operate near full capacity. As the reservoir level rises, the number of moules for production of water are reduced, and there is a greater amount of power production from the dual purpose desalting plant.

2.4 Cases Considered for Analysis.

Two general conjunctive systems have been described in Section 2.2, and the mathematical models for computation

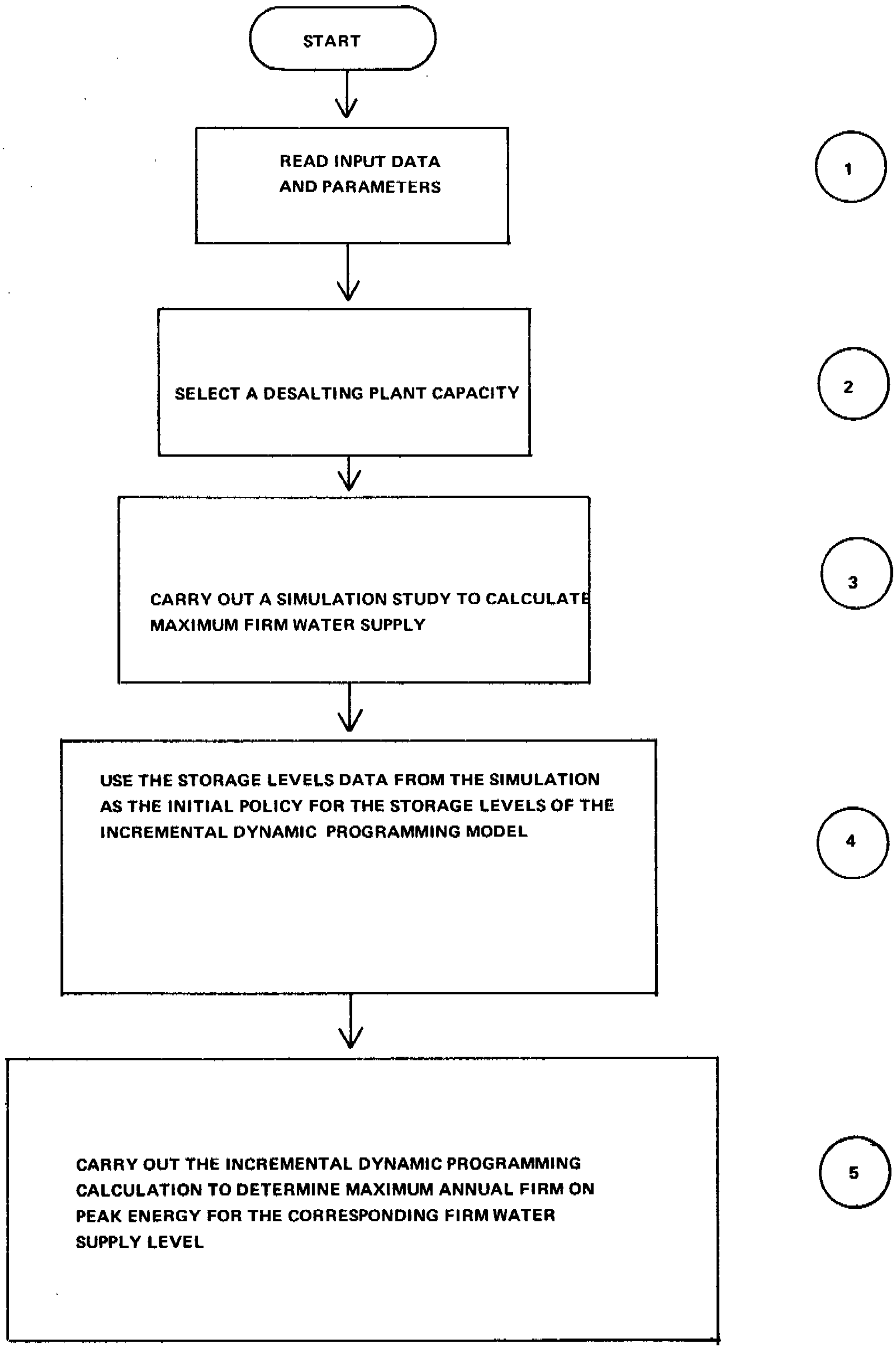


Figure 2.5 Master Flow Chart for the Total System

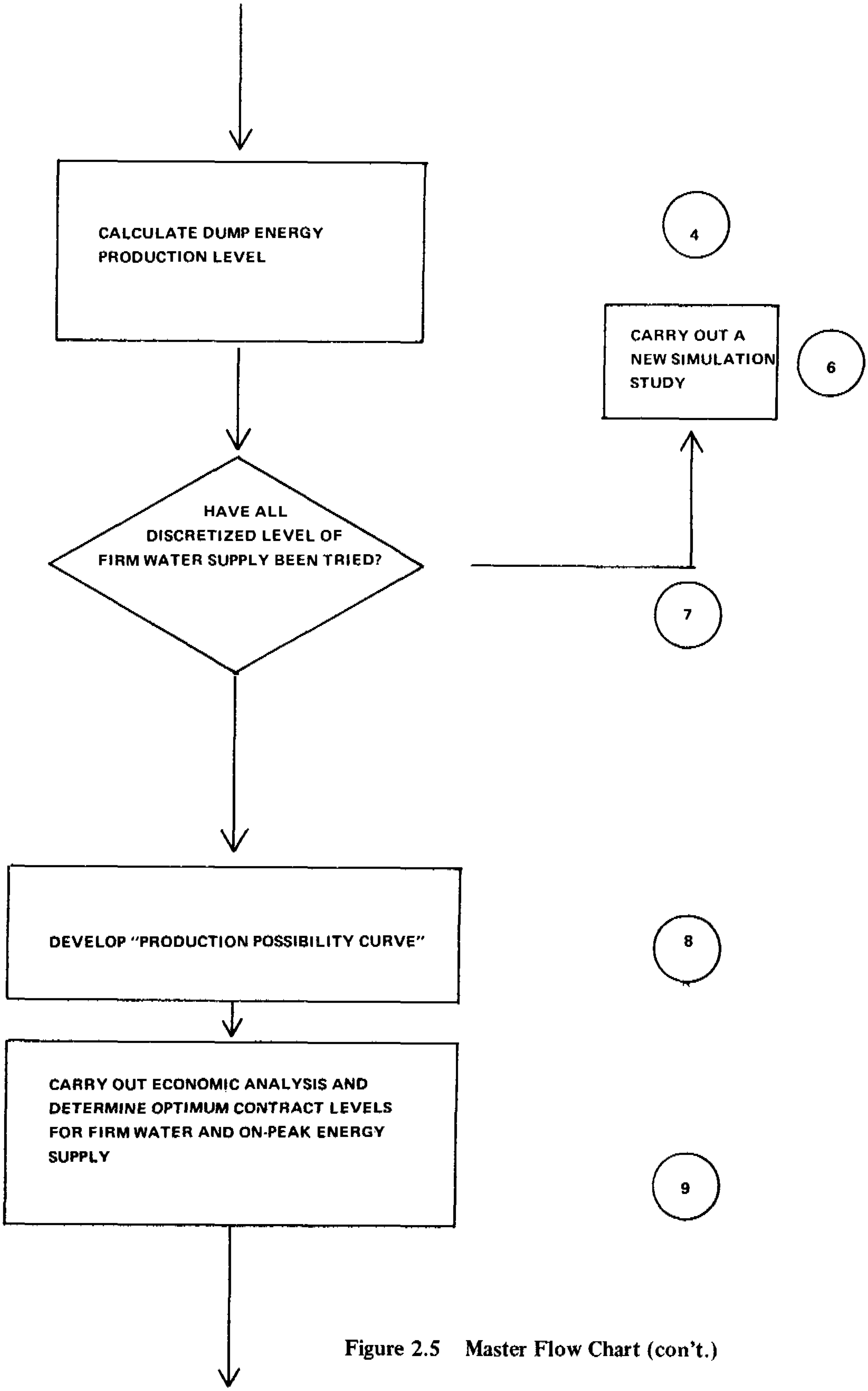
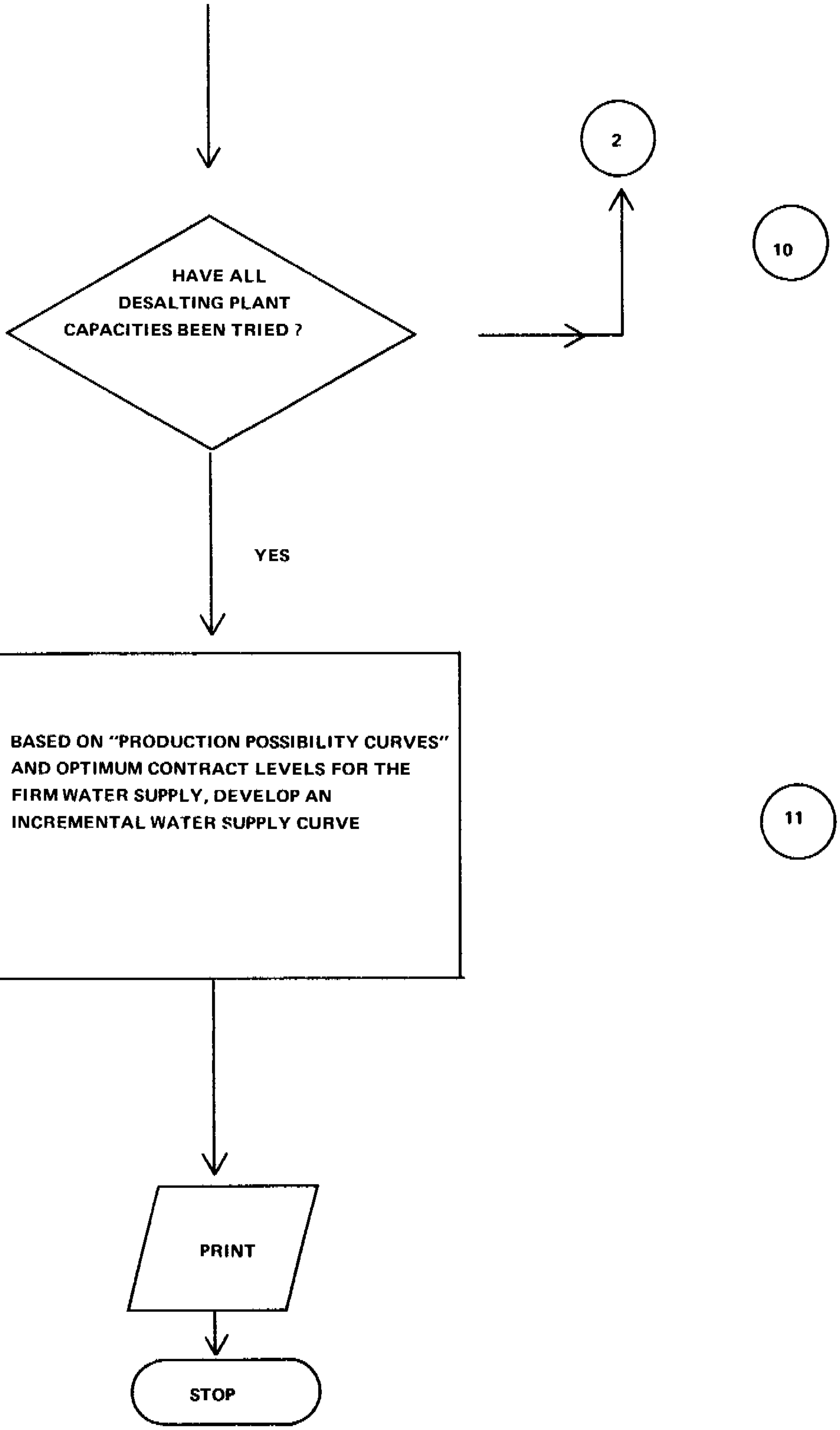


Figure 2.5 Master Flow Chart (con't.)



NOTE:

Only steps 1 to 6 are computerized
The rest of the steps are easily computed on
a desk calculator

Figure 2.5 Master Flow Chart (con't.)

are developed in Appendix A. A systematic procedure is adopted to establish the economic feasibility of conjunctive systems. The computations are carried out as detailed below.

A. Series Reservoir Conjunctive System.

Case A1 Reservoir Operation

(1) For the reservoir system, compute the maximum firm water yield by simulation.

(2) Compute the firm and dump energy production from the above system, using an incremental dynamic programming algorithm.

(3) For specified firm water levels, compute firm and dump energy for the system, to establish the "production possibility curve," which shows the relation between firm water and power outputs.

(4) Calculate the optimum contract levels for firm water and power.

Case A2 Desalting Plant Base Load

(1) Calculate the maximum firm water yield when the desalting plant is operated by itself, based on the monthly water requirement distribution for the region.

(2) Calculate the dump energy production from desalting plants.

(3) Calculate unit cost of firm water supply.

Case A3 Desalting Plant Operated With a Smaller Reservoir to Regulate Water from Desalination

(1) Calculate the firm water yields when the desalting plant is operated conjunctively with a small reservoir. (See Table 4.6 for reservoir sizes.)

(2) Calculate the firm and dump energies.

(3) Calculate the unit cost of the incremental supply of firm water.

Case A4 Conjunctive System

(1) Compute the maximum firm water yield by simulation, for the conjunctive system.

(2) Compute the firm and dump energy production

for the conjunctive system, using an incremental dynamic programming algorithm.

(3) Establish the production possibility curve, as in Case 1.

(4) Calculate the optimum contract levels for firm water and power, and the optimum unit cost of the incremental supply of firm water.

Case A5 Study of the Reservoir System and Conjunctive System Under Altered Conditions

Carry out the analysis as in Case A1 and A4, when

(1) Stream flow conditions are more critical, *i.e.*, runoff is low.

(2) Stream flow conditions are less critical, *i.e.*, runoff is high.

(3) Reservoirs are smaller in size.

Cases A2 to A4 are carried out for five different capacities for the dual purpose desalting plants, to determine the effect of size on conjunctive operation. Case A5 is illustrative of how changes in physical parameters and conditions affect the conjunctive operation, and thus only one desalting plant size is considered.

B. Parallel Reservoir Conjunctive System

Case B1 Reservoir Operation

Carry out analysis as in Case A1.

Case B2 Conjunctive System

Carry out the analysis as in Case A4.

CHAPTER 3
ECONOMIC ANALYSIS

The underlying motivation for the concept of conjunctive systems is the additional economic benefit which can be derived from such operation, as opposed to the operation of surface reservoirs and desalting plants separately. Mathematical equations are developed to carry out an economic analysis for this conjunctive system.

3.1 Desalting Plant Costs. (Case A2)

The cost of a desalting plant is a function of the capacity of the plant, the load factor, steam cost, and the variable costs. As explained in the previous chapter, the steam cost for the operation of a desalting plant will remain the same for a fixed size of desalting plant. A firm level of low pressure steam is contracted and used for water production and/or energy production in low pressure turbogenerators, as the case may be.

The cost associated with desalting plant operation is generally reported in terms of quantity of water produced, i.e., ¢/1000 gallons. Knowing the plant size and load factors, the annual quantity of water production, and hence the annual costs can be determined. Thus if the unit costs are F ¢/1000 gallons, the annual fixed cost will be given by

Annual Cost = (F) (DY) (L.F) (CAPDES) x 10 \$ ±3.1.11

Where

F = Unit cost in ¢/1000 gallons

DY = Days in a year

L.F = Operating plant load factor

CAPDES = Desalting plant capacity in MGD (million gallons per day)

If operation is at full load,

Annual Cost = (F) (DY) (CAPDES) x 10 \$ ±3.1.21

If (as is generally the case with fixed costs), costs are given in terms of the total present worth values, that is, the dollar investment to be made at present is P\$, the annual cost can be computed. (Taxes and profits are not included, since the ownership of the system is a question outside of the scope of this study. At any rate, they are the same if the plant is operated independently or in conjunction with the reservoir system, so they enter the calculations in a nonessential way.) Using an economic life of 3 years and a 5% interest rate, the annual cost will be given by

$$\text{Annual Cost} = P \times CR_{i}^{n} \qquad [3.1.3]$$

where

CR_{i}^{n} = Capital Recovery factor (.06588 for $i = 5\%$ and $n = 30$ years)

The actual annual production of water from a desalting plant can be computed from

$$AFW_D = (L.F)\ (CAPDES)\ (a)\ (DY) \qquad [3.1.4]$$

where

AFW_D = Annual desalted firm water production in KAF (1000 acre-feet).

a = Conversion factor from millions of gallons to 10^3AF (.0030689)

The total annual cost of desalting and electricity produced by low pressure turbogenerator may be calculated by the following equation:

$$ACOST_D = AFC + ASC + AOMC + ALPTC \qquad [3.1.5]$$

where

$ACOST_D$ = Annual cost of desalting plant

AFC = Annual fixed cost of the desalting plant

ASC = Annual Steam Costs

AOMC = Annual Operation and Maintenance Costs

ALPTC = Annual Low Pressure Turbine Costs

A dual purpose plant may also produce some firm on-peak energy and dump energy, when the operation of the water plant is at a low load factor. This energy can be sold, and thus a net benefit can be derived from power production, thereby reducing the annual costs that are charged for water production. Thus, if AFE_D and $EVADE_D$ represent the annual firm energy and equivalent uniform annual dump energy production from the desalting plant, and FEP and DEP are the unit firm energy and dump energy prices, then the revenue generated due to energy production from the desalting plant is given by

$$REV_D = (AFE_D)\ (FEP) + (EVADE_D)\ (DEP) \qquad [3.1.6]$$

where

REV_D = The annual revenue from the sale of energy from desalting.

When a desalting plant is operated by itself, the energy production is due to the low grade steam passing through the low pressure turbo generators, and hence there can be no firm energy production. Thus we have

$$AFE_D = 0 \qquad [3.1.7]$$

and $$REV_D = (EVADE_D)\ (DEP) \qquad [3.1.8]$$

Then the unit cost of water production, $UNCOST_D$, is given by

$$UNCOST_D = \frac{ACOST_D - REV_D}{AFW_D} \quad \$/AF \qquad [3.1.9]$$

3.2 Desalting Plant Operation With a Small Reservoir (Case A3)

When a desalting plant is operated by itself, it remains idle during the periods when water requirements are low. If a small regulating reservoir is built and operated with a desalting plant, the firm level of water output can be increased. The desalting plant can be operated at full load, and when water production exceeds demand, it is stored in the reservoir, to be used in dry periods. No energy can be produced, as the reservoir is used merely to increase the firm water output of the system. The low pressure turbine generator is not required for this system, and the annual desalting plant costs are reduced. If the annual reservoir cost is ARCOST, then using the notation of Section 3.1,

$$UNCOST_D = \frac{ACOST_D + ARCOST - ALPTC}{AFW} \qquad [3.2.1]$$

3.3 Analysis of a Conjunctive System

When a desalting plant is operated conjunctively with an existing surface system, the water and energy yields increase considerably. When operated by itself, the maximum annual firm water, annual firm on-peak energy and dump energy productions for the surface system can be determined from the computational runs, and any increase in production over these levels can be attributed to conjunctive operation.

For the conjunctive operation, the production possibility curves for each size of desalting plant are determined. Any point on this curve gives the maximum firm energy production, for a given level of firm water output. Thus, the net increases in firm water, firm on peak energy, and dump energy, over the levels obtained from operating the reservoir system at the maximum firm water level, will be given by

$$\Delta AFW = AFW_C - AFW_{R*} \quad [3.3.1]$$

$$\Delta AFE = AFE_C - AFE_{R*} \quad [3.3.2]$$

$$\Delta EVADE = EVADE_C - EVADE_{R*} - EVADE_D \quad [3.3.3]$$

where

AFW and AFE give the annual firm water and firm energy levels, respectively.

EVADE gives the equivalent annual dump energy production

and the subscripts C, R and D represent conjunctive system, reservoir system, and desalting plant, and * corresponds to the maximum firm water output levels.

As will be apparent from the next two equations, the increment in dump energy is defined differently than the increment in firm water because the energy change will be treated as a reduction in the cost of water.

The net annual revenue from sale of additional energy due to conjunctive operation of the desalting plant with the reservoir can then be computed:

$$REV_C = (\Delta AFE)\ (FEP) + (\Delta EVADE)\ (DEP) \quad [3.3.4]$$

Where FEP and DEP are unit price for firm and dump energy respectively. The conjunctive operation also results in an increased water production. Using equation [3.1.5] for the annual cost of the desalting plant, and equation [3.3.4] for the revenue from sale of energy, the unit cost of additional firm water for the conjunctive system will be

$$UNCOST_C = \frac{ACOST_D - REV_C}{\Delta AFW} \quad \$/AF \qquad [3.3.5]$$

Now, for any point on the production possibility curve for conjunctive operation, the unit cost of additional firm water is determined from Equation 3.3.5, and thus the optimum point of operation, that is, one which gives the minimum unit cost, is established.

This analysis is carried out for conjunctive operation with five sizes of desalting plants, and a curve can then be developed to represent the least unit cost for additional quantities of firm water from conjunctive operaion. Thus, if the quantity of additional firm water required is known for a region, the curve can be used to get the unit cost of the additional firm water, and also the desalting plant size. (The annual cost can also be calculated from this information and the method is shown in the next chapter.) This can be compared with the unit and annual cost of water from alternate sources of supply, to decide on the source of firm water to be used for meeting the future requirements.

A similar analysis is carried out for a parallel reservoir system, to compute the unit water costs obtained when it is operated conjunctively.

CHAPTER 4
APPLICATION OF MODELS DEVELOPED AND COMPUTATIONAL RESULTS

The computational models developed and discussed in the Appendix are applied to system configurations as described in Chapter 2. A 10-year critical hydrology period is selected from actual watershed records, modified somewhat to fit the reservoir system studied. Since the analysis is in one month intervals, there are 120 one-month time periods to be considered. The monthly hydrological data (the inflows, evaporation rates, flood control and water quality requirements), and the physical parameters for the system (reservoir sizes, minimum and maximum storage levels, dead storage levels, power plant capacity) are based on hypothetical data. The data or rather, assumed values used for analysis, and the format required for using these values, are specified in Appendix A and are given in detail in Appendix B under "System Characteristics."

The main parameters for the series system are, however, the following. The storage sizes are 985,000 AF for reservoir 1 and 1,248,000 AF for reservoir 3. Reservoirs 2 and 4 are constant head reservoirs of about 100,000 AF storage capacity.

The two domestic water demands are (P1) 11,000 AF/year and (P2) 39,000 AF/year. In addition, there is a large irrigation demand (P3) of assumed size 517,000 AF/year.

4.1 Analysis of Reservoir Operation. Case A1.

The simulation run determines the maximum firm water yield from the 4-reservoir series system. The dynamic programming routine then determines the maximum possible firm on-peak and dump energy productions at the maximum level of firm water production. Using the notation developed in Chapter 3, we have:

$$AFW_{R*} = 332.5 \text{ KAF}$$

$$AFE_{R*} = 71 \times 10^3 \text{ MWH}$$

$$EVADE_{R*} = 232 \times 10^3 \text{ MWH}$$

By varying the annual firm water output level, the firm and dump energy productions are computed (Table 4.1).

The production possibility curve can then be drawn, and is given in Figure 4.1 (See Section 4.5).

4.2 Desalting Plant Operation. Case A2

Various types of dual-purpose desalting plants could be used for the conjunctive system under consideration. Further nuclear or fossil fuel plants can be employed. The actual design of the plant, however, enters into this study in the form of power-water tradeoffs and operating and amortized capital costs. For these purposes, data for typical representative plants, as supplied by the Oak Ridge National Laboratory,* were used in the study. The various categories of costs employed are illustrated in tables in Appendix D. It should be noted that these costs do not include expenses of pumping water beyond the plant boundaries.

Five different sizes of desalting plants (100, 150, 200, 250 and 300 MGD) are considered for analysis in this study. Each plant comprises 4 modules of equal capacity.

The full load water production in every month can be calculated from Equation 3.1.4. For a 100-MGD desalting plant, the full load production in January (DY = 31) will thus be given by

$$\text{Water Production Capacity} = 1.0 \times 100 \times .0030689 \times 31$$

$$= 9.51 \text{ KAF}$$

The per module capacity for January will be one fourth the monthly capacity, thus

Per Module Capacity = 2.38 KAF

These capacities can be computed in every month for all plant sizes, and are given in Table 4.2.

The operation of the desalting plant is carried out on the basis of the demand distribution for the region under consideration. During one year of operation, the water requirements in any month are some percentage of the total consumption during the year. Thus, the fractional demand of every month (β_n) is calculated and gives the monthly demand distribution (see Table 4.3).

When the monthly requirements are maximum (in July, the fractional demand $\beta_7 = .140$), the desalting plant must be operated to produce the maximum amount of water possible. Thus, all 4 modules produce water, and for

---

* Personal communications from H. R. Payne, September 2, 1970, February 23, 1971, and March 5, 1971. Some of these data are derived from the report ORNL-TM-1564, Flexibility in Production of Power and Water from Nuclear Desalting Plants, by J. K. Franzreb and I. Spiewak, Oak Ridge National Laboratory, Oak Ridge, Tenn.

TABLE 4.1

RESULTS FROM COMPUTER RUNS FOR

RESERVOIR OPERATION

(Case A1)

Annual Firm Water (AFW) KAF	Annual Firm Energy (AFE) 10^3MWH	Equivalent Annual Dump Energy (EVADE) 10^3MWH
332.5	71	232
300	128	195
200	201	164
100	222	88
0	228	70

a 100 MGD plant, 9.51 KAF of water are produced in July. For the remaining months, the water quantity produced can be calculated as a fraction of that in July. For example, in June, the quantity of water produced from a 100 MGD desalting plant will be given by

$$\text{Water Quantity} = \frac{\beta_6}{\beta_7} \times 9.51 = \frac{.107}{.140} \times 9.51 = 7.26 \text{ KAF}$$

(June 100 MGD plant)

From Table 4.2, the per module capacity for each plant size in each month can be used to compute the number of modules in operation in each month for water production.

The data for tradeoff between water and power are given in Appendix D, Tables D.1 to D.5, for different sized desalting plants. From the runs for conjunctive operation discussed in a later section (4.5), the load factors for desalting plants are determined, and it is assumed that the nuclear plants operate at these load factors to produce power. Thus, for a 100 MGD plant, the load factor is 45.8%, and by interpolating, the turbogenerator capacities are obtained. In January, the dump energy production for a 100 MGD plant will be given by

$$
\begin{aligned}
DE_{\text{January}} &= \text{Turbogenerator Capacity} \times \text{Total hours} \\
&= 109 \times 31 \times 24 \\
&= 81.1 \times 10^3 \text{ MWH}
\end{aligned}
$$

Carrying out the calculations for all months, the annual firm water yield and dump energy production are derived from the sum of the monthly productions. The operation of the desalting plants is summarized in Table 4.3.

To calculate the unit cost of desalted water, the annual desalting plant costs must be determined. Cost data used for desalting plants is summarized in Appendix D. Tables D.6 to D.10 give the total unit water costs. Tables D.11 to D.15 give the unit fixed costs. Table D.16 gives the steam costs. Tables D.17 to D.21 give the unit fixed costs and the total capital costs for the low pressure turbogenerator (LPTG). A sample calculation for the 100 MGD plant illustrates the use of this data for calculation of desalting plant costs.

4.3 Sample Calculation for Desalting Plant Costs.

It is assumed that the desalting plants are

TABLE 4.2

WATER PRODUCTION CAPACITY OF DESALTING PLANTS

	CAPACITY PER MODULE FOR DESALTING PLANTS IN 10^3AF											
MONTH	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
DAYS IN MONTH	31	28	31	30	31	30	31	31	30	31	30	31
PLANT SIZE MGD												
100	2.38	2.15	2.38	2.30	2.38	2.30	2.38	2.38	2.30	2.38	2.30	2.38
150	3.57	3.22	3.57	3.45	3.57	3.45	3.57	3.57	3.45	3.57	3.45	3.57
200	4.76	4.30	4.76	4.60	4.76	4.60	4.76	4.76	4.60	4.76	4.60	4.76
250	5.95	5.37	5.95	5.75	5.95	5.75	5.95	5.95	5.75	5.95	5.75	5.95
300	7.13	6.44	7.13	6.90	7.13	6.90	7.13	7.13	6.90	7.13	6.90	7.13

(I.e., the reason production capacity for a given plant size is different for various months is merely that the number of days per month are different.)

designed and operated optimally. Thus, if the operating load factor is 10%, the design load factor also equals 10%.

For a 10% design and operating load factor, we have for a 100 MGD plant:

Total Unit Cost = 86.3 ¢/1000 gal (Table D.6)

Fixed Unit Cost = 66.9 ¢/1000 gal (Table D.11)

∴ Variable Unit Cost = 86.3 - 66.9 = 19.4 ¢/1000 gal.

Since it is stipulated that firm steam is contracted for on the basis of 100% design and operating load factors, an extrapolation of Table D.16 gives

Firm Unit Steam Cost = 12.5 ¢/1000 gal (Table D.16)

Now, the variable costs are the operation and maintenance (OM) costs, and steam costs. For this, the steam costs will be as in Table D.16, for low cost steam, which at 10% design and operation = 11.4 ¢/1000 gal.

∴ OM & Misc. Unit Costs = Variable Unit Cost

    - Steam Unit Cost

    = 8.0 ¢/1000 gal.

The capital cost for the LPTG is taken from Table D.17

LPTG fixed cost = 17.0×10^6 \$

Using the notation in Chapter 3, we then have, from Equations 3.1.1, 3.1.2, and 3.1.3

AFC = Fixed Unit Cost ¢/1000 gal x (CAPDES) x (L.F) x DY x 10

= 66.9 x 100 x .1 x 365 x 10 \$

= 2.44×10^6 \$

AOMC = Unit OM Costs ¢/1000 gal x (CAPDES) x (L.F) x DY x 10

= 8.0 x 100 x .1 x 365 x 10 \$

= $.29 \times 10^6$ \$

$$ASC = \underset{\text{¢/1000 gal}}{\text{Unit Steam Costs}} \times (CAPDES) \times DY \times 10$$

$$= 12.5 \times 100 \times 365 \times 10 \ \$$$

$$= 4.56 \times 10^6 \ \$$$

The annual LPTG costs can be computed from a capital recovery formula for an economic life of 30% at 5%, a rate commonly used by government agencies in the field of water resources development.

$$\therefore \quad ALPTC \quad - \quad 17.0 \times 10^6 \begin{bmatrix} CR \\ n=30 \\ i=5\% \end{bmatrix}$$

$$= 17.0 \times .06588 \times 10^6$$

$$= 1.12 \times 10^6 \ \$$$

From Equation 3.1.5, we get

$$ACOST_D = (2.44 + .29 + 4.56 + 1.12) \times 10^6$$

$$= 8.41 \times 10^6 \ \$$$

The cost calculations for the different sized desalting plants are given in Tables D.22 to D.26. From these tables, the cost of desalting plants for operating at the load factors obtained from computations (Section 4.5), can be determined, and the unit water costs calculated from Equation 3.1.9. The calculations are made by assuming a price for the firm and dump energies (for example, \$6/MWH for firm energy and \$1/MWH for dump energy). The unit costs can then be calculated. As expected from the lack of economies of scale in this area of operation, the unit costs are quite constant. They are given in Table 4.4.

4.4 Desalting Plant Operated With a Small Reservoir Case A3

The production of water, when the desalting plant is operated by itself has been summarized in Table 4.3. However, in this case, the plant is operating below capacity except for 3 months, when all the 4 modules are operating for water production. Thus, if a small reservoir is constructed to operate with the desalting plant, then water produced in the months when demand is low can be used in later months, thereby increasing the firm water level. An analysis can be carried out along these lines to calculate the minimum size of the "small" reservoir, and the initial storage required for conjunctive operation. Sample calculations

TABLE 4.3

DESALTING PLANT OPERATION

(Case A2)

PLANT SIZE	MONTH	J	F	M	A	M	J	J	A	S	O	N	D
	Distrib.*	.061	.055	.065	.070	.075	.107	.140	.130	.094	.077	.065	.061
β_n													
100 MGD	Qty KAF+	4.10	3.70	4.37	4.70	5.04	7.26	9.51	8.74	6.32	5.18	4.37	4.10
	Modules for water	2	2	2	3	3	4	4	4	3	3	2	2
	Nucl. Cap MW	109	109	109	55	55	0	0	0	55	55	109	109
	10^3 MWH	81.9	73.2	81.1	39.6	40.9	–	–	–	39.6	40.9	78.5	81.1
150 MGD	Qty KAF	6.15	5.54	6.55	7.06	7.56	10.79	14.11	13.11	9.48	7.76	6.55	6.15
	Modules for water	2	2	2	3	3	4	4	4	3	3	2	2
	Nucl. Cap MW	162	162	162	81	81	0	0	0	81	81	162	162
	10^3 MWH	120.5	108.9	120.5	58.3	60.3	–	–	–	58.3	60.3	116.6	120.5
200 MGD	Qty KAF	8.20	7.39	8.75	9.41	10.08	14.38	18.82	17.48	12.64	10.35	8.74	8.20
	Modules for water	2	2	2	3	3	4	4	4	3	3	2	2
	Nucl. Cap MW	208	208	208	105	105	0	0	0	105	105	208	208
	10^3 MWH	154.8	139.8	154.8	75.6	78.1	–	–	–	75.6	78.1	149.8	154.8
250 MGD	Qty KAF	10.25	9.24	10.92	11.76	12.60	17.98	23.52	21.84	15.79	12.94	10.92	10.25
	Modules for water	2	2	2	3	3	4	4	4	3	3	2	2
	Nucl. Cap. MW	252	252	252	126	126	0	0	0	126	126	252	252
	10^3 MWH	187.5	169.3	187.5	90.7	93.7	0	0	0	90.7	93.7	181.4	187.5

TABLE 4.3 (Cont'd)

PLANT SIZE	MONTH	J	F	M	A	M	J	J	A	S	O	N	D
	Distrib. β_n	.061	.055	.065	.070	.075	.107	.140	.130	.094	.077	.065	.061
300 MGD	Qty KAF	12.30	11.09	13.11	14.11	15.12	21.57	28.23	26.22	18.95	15.53	13.11	12.30
	Modules for water	2	2	2	3	3	4	4	4	3	3	2	2
	Nucl. Cap. MW	302	302	302	152	152	0	0	0	152	152	302	302
	10^3 MWH	224.7	202.9	224.7	109.4	113.1	-	-	-	109.4	113.1	217.4	224.7

For 100 MGD, Total Annual Firm Water is 67 KAF, Dump Energy 556 x 10^3 MWH
150 MGD, Total Annual Firm Water is 101 KAF, Dump Energy 824 x 10^3 MWH
200 MGD, Total Annual Firm Water is 134 KAF, Dump Energy 1061 x 10^3 MWH
250 MGD, Total Annual Firm Water is 168 KAF, Dump Energy 1282 x 10^3 MWH
300 MGD, Total Annual Firm Water is 201 KAF, Dump Energy 1539 x 10^3 MWH

* Assumed
+ KAF = 1000 acre-feet

are shown for a 100 MGD plant. A maximum safe plant load of 85% is used for the computations.

All the water demands are to be met by water production from the desalting plant. The quantity of water produced is treated as an inflow into the reservoir, from where water is drawn off to meet demands. In addition to external demands, some of the water is used up due to evaporation from the reservoirs. The evaporation rates for each month are taken from the hydrological data of the region. Now, if the physical characteristics of the reservoir are assumed (linear relation for Area and Storage = 0.087 KA/KAF), then the evaporation in any period can be calculated from the storage level in the reservoir. A mass balance relation is used to calculate storage levels.

$$S_{E,n} = S_{I,n} + I_n - R_n \qquad [4.4.1]$$

where $S_{E,n}$ = Storage of the reservoir at end of period n.

$S_{I,n}$ = The Initial Storage of the reservoir in period n.

I_n = Inflow into reservoir in period n.

R_n = The total requirements to be met in period n (evaporation and external demands).

The inflow in any month will be given by the water production in that month, and can be computed from Equation 3.1.4, where DY now gives the number of days in a month. Thus, if I_n is the monthly production then the quantity of water produced in a year is given by

$$ADW = \sum_{n=1}^{12} I_n \text{ KAF} \qquad [4.4.2]$$

where ADW = Annual desalted water production.

Now, if the evaporation rate in any month is ER_n, and the reservoir area A_n, the monthly evaporation is given by

$$EV_n = ER_n A_n \qquad [4.4.3]$$

The annual firm water supply will then be given by

$$AFW = \sum_{n=1}^{12} (R_n - EV_n) \qquad [4.4.4]$$

TABLE 4.4

UNIT COST OF DESALTED WATER

(Case A2)

PLANT SIZE MGD	LOAD FACTORS (%)	FIRM ANNUAL SUPPLY 10^3 AF	ANNUAL BENEFIT FROM DUMP ENERGY 10^3\$ *	TOTAL COST CHARGED TO WATER 10^3\$	ANNUAL COST OF WATER+ 10^3\$	UNIT WATER COST \$/ AF	¢/1000 Gal.
100	45.8	67	556	9,350	8,794	131	40.2
150	49.5	101	824	13,860	13,036	129	39.6
200	56.6	134	1,061	18,800	17,739	132	40.5
250	60.0	168	1,282	23,570	22,288	133	40.8
300	60.0	201	1,539	28,000	26,461	132	40.5

* at \$1/MWH

\+ Based on Oak Ridge National Laboratories Data, Appendix D

The demand follows a distribution pattern during the year (see Table 4.3 for distribution pattern). Thus, the demand in any month is given by

$$R_n = \beta_n \times ADW \qquad [4.4.5]$$

Table 4.5 gives the summary calculations for reservoir size, with a 100 MGD desalting plant at 85% load factor. It is first assumed that the initial storage in the reservoir is zero, and the ending storage in each period is calculated from Equation [4.4.1]. From this, it is seen that to maintain a firm ADW = 95.22 KAF, the reservoir storage falls short by a maximum of 4.68 KAF. Now, the surface area of the reservoir can be determined from the average storage level in any month, thus

$$A_n = \frac{S_{E,n} + S_{I,n}}{2} \qquad [4.4.6]$$

The monthly evaporation can now be calculated from Equation [4.4.3], and monthly water production to meet external supply will be given by

$$\text{Monthly production} = R_n - EV_n \qquad [4.4.7]$$

Equation [4.4.4] then gives the annual firm water production from the system.

Similar calculations are carried out for the desalting plant units of 150, 200, 250, and 300 MGD capacities. Table 4.6 gives the sizes of reservoirs required (to the next higher integer), and annual firm water supplies obtained from such a conjunctive operation. Reservoir costs are then computed using the approximate relations:

Capital Cost	=	\$60/AF for reservoir size about 10KAF
of Reservoir		\$40/AF for reservoir size about 100KAF
		15600 \$/yr for 10KAF reservoir
O & M Costs	=	25000 \$/yr for 20 KAF reservoir

An economic life of 50 years and a 5% interest rate is used for computing annual costs from capital costs.

Cost data taken from: Spiegler, K.S., "Principles of Desalination," A.P. (New York) 1967, for region 3 in Table 11.2. Note that most reservoir cost variations, secular or geographical, would not alter the study conclusions.

TABLE 4.5

DESALTING PLANT IN CONJUNCTION WITH A SMALL RESERVOIR

(Case A3)

Physical Characteristics Area/Storage = .087 KA/KAF (1000 acres/1000 acre-feet) for Reservoir

MONTH	n	DEMAND DISTRI. FACTOR β_n	ER_n* FT/MO UNIT AREA	I_n INFLOW KAF	R_n DEMANDS KAF	$S_{I,n}$ KAF	$S_{E,n}$ KAF	NEW $S_{I,n}$ KAF	NEW $S_{E,n}$ KAF	EV_n KAF	FIRM WATER FOR SUPPLY KAF
Jan	1	.061	.20	8.09	5.81	0.00	2.28	4.68	6.96	.10	5.71
Feb	2	.055	.19	7.31	5.24	2.28	4.35	6.96	9.03	.13	5.11
Mar	3	.065	.32	8.09	6.19	4.35	6.25	9.03	10.93	.28	5.91
Apr	4	.070	.37	7.82	6.67	6.25	7.40	10.93	12.08	.37	6.30
May	5	.075	.43	8.09	7.14	7.40	8.35	12.08	13.03	.47	6.67
Jun	6	.107	.64	7.82	10.19	8.35	5.98	13.03	10.66	.66	9.53
Jul	7	.140	.81	8.09	13.33	5.98	.74	10.66	5.42	.57	12.76
Aug	8	.130	.90	8.09	12.38	.74	-3.55	5.42	1.87	.29	12.09
Sep	9	.094	.67	7.82	8.95	-3.55	-4.68	1.87	0.0	.05	8.90
Oct	10	.077	.54	8.09	7.33	-4.68	-3.92	0.0	.76	.02	7.31
Nov	11	.065	.40	7.82	6.19	-3.92	-2.29	.76	2.39	.05	6.14
Dec	12	.061	.27	8.09	5.81	-2.29	0.0	2.39	4.68	.08	5.73
TOTAL		1.0		95.22	95.23					3.07	95.16

*Note: Subscript n signifies month, KAF = 1000 acre-feet, ER_n is evaporation rate, I_n is inflow into reservoirs, $\bar{R}_n$ is water demand, $S_{I,n}$ is initial reservoir storage, $S_{E,n}$ is final storage, EV_n is the actual evaporation.

TABLE 4.6

UNIT WATER COSTS WHEN DESALTING PLANT

IS OPERATED WITH A SMALL RESERVOIR

(Case A3)

(Low Pressure Turbine Costs are Not Included

in Desalting Plant Costs)

PLANT SIZE	RESERVOIR SIZE, 1000AF	ANNUAL COST OF RESERVOIR 10^3 \$ Fixed	O & M	ANNUAL COST OF DESALTING PLANT 10^3 \$	ANNUAL FIRM WATER 1000AF	\$/AF	UNIT WATER COST ¢/1000 gal.
100	14	45	20	10,330	92	113	34.7
150	20	63	25	15,170	138	111	34.1
200	27	83	26	19,980	183	110	33.8
250	33	100	27	24,810	230	108	33.1
300	40	117	30	29,590	276	108	33.1

The costs for the desalting plants are derived from Tables D.22 to D.26 for an 85% operation and design factor. However, the annual cost of low pressure turbines should not be included in desalting plant costs for this case, as they are not required. The unit water cost can be calculated from Equation [3.2.1].

4.5 Conjunctive System Operation. Case A4.

The series reservoir system described in Figure 2.3 is used conjunctively with different sizes of desalting plants. Details of computation are given for a 100 MGD plant, and computation for other plant sizes is carried out in the same manner.

Where a desalting plant is being used conjunctively, it is important to determine the load factor. In the computations, an initial load factor is assumed, and the power plant capacity for production of electricity at this load factor is fed in as input data. After the optimization run, the output specifies the amount of water to be derived from the desalting plants, and the modules in operation during the analysis. From this, an actual operating load factor is computed. The new load factor is then used in the next set of computations, and this successive iteration process is used to determine the optimal load factor for the operation of the desalting plant. The plant costs are then determined from Tables D.22 to D.26, based on this load factor, to use for calculating the water costs.

The simulation model determines the maximum firm water level, and the corresponding firm and dump energies. The production possibility curve is then determined, by computing energy outputs at specified levels of firm water supply. The results from computer runs for the different cases are given in Table 4.7, and the production possibility curves are drawn in Figure 4.1.

From the production possibility curve, 6 to 8 points are selected close to the maximum firm water yield, to compute the unit water costs. The maximum firm water yield, and the firm and dump energy productions for the reservoir operation are then taken from Section 4.1. For any point on the production possibility curve, the firm water and firm energy productions can be read off directly from Figure 4.1. The equivalent annual dump energies are derived by interpolation between the numbers obtained in Table 4.7. Thus, for the 100 MGD case, the dump energy levels are known when firm water levels are 445KAF and 425 KAF. By an approximate interpolation, the dump energy production when firm water is 435KAF, can be determined.

Equations [3.3.1], [3.3.2] and [3.3.3] are then used to calculate the increases in energy and water productions,

TABLE 4.7

RESULTS OF COMPUTATION RUNS

(Case A4)

(Conjunctive Operation)

PLANT	100 MGD (LF=45.8%)			150 MGD (LF=49.5%)			200 MGD (LF=56.6%)			250 MGD (LF=60%)			300 MGD (LF=60%)		
SIZE	AFW* KAF	AFE 10^3MWH	EVADE 10^3MWH	AFW KAF	AFE 10^3MWH	EVADE 10^3MWH	AFW KAF	AFE 10^3MWH	EVADE 10^3MWH	AFW KAF	AFE 10^3MWH	EVADE 10^3MWH	AFW KAF	AFE 10^3MWH	EVADE 10^3MWH
	445	242	1177	500	215	1698	557.5	139	1950	612.5	136	1942	667.5	602	1959
	425	680	1007	475	944	1499	550	498	1850	600	191	2368	650	750	2218
	400	857	1076	465	860	1374	525	653	1950	550	1310	2178	600	1250	2470
	345	882	1126	450	1011	1515	512.5	1429	1598	525	1420	2303	550	1713	2307
	320	885	1153	425	1229	1408	500	1507	1600	500	1594	2211	500	1978	2406
	175	999	1086	400	1299	1338	425	1600	1635	450	2037	1995	345	2311	2262
	0	1098	1020	345	1316	1526	345	1554	1755	400	2073	2142	320	2268	2369
				320	1307	1436	320	1638	1902	345	2108	2193	0	2484	3029
				0	1480	1573	0	1805	2130	320	2110	2048			
										0	2252	2695			

*AFW = annual firm water, AFE = annual firm energy, EVADE = equivalent annual dump energy, LF = load factor.

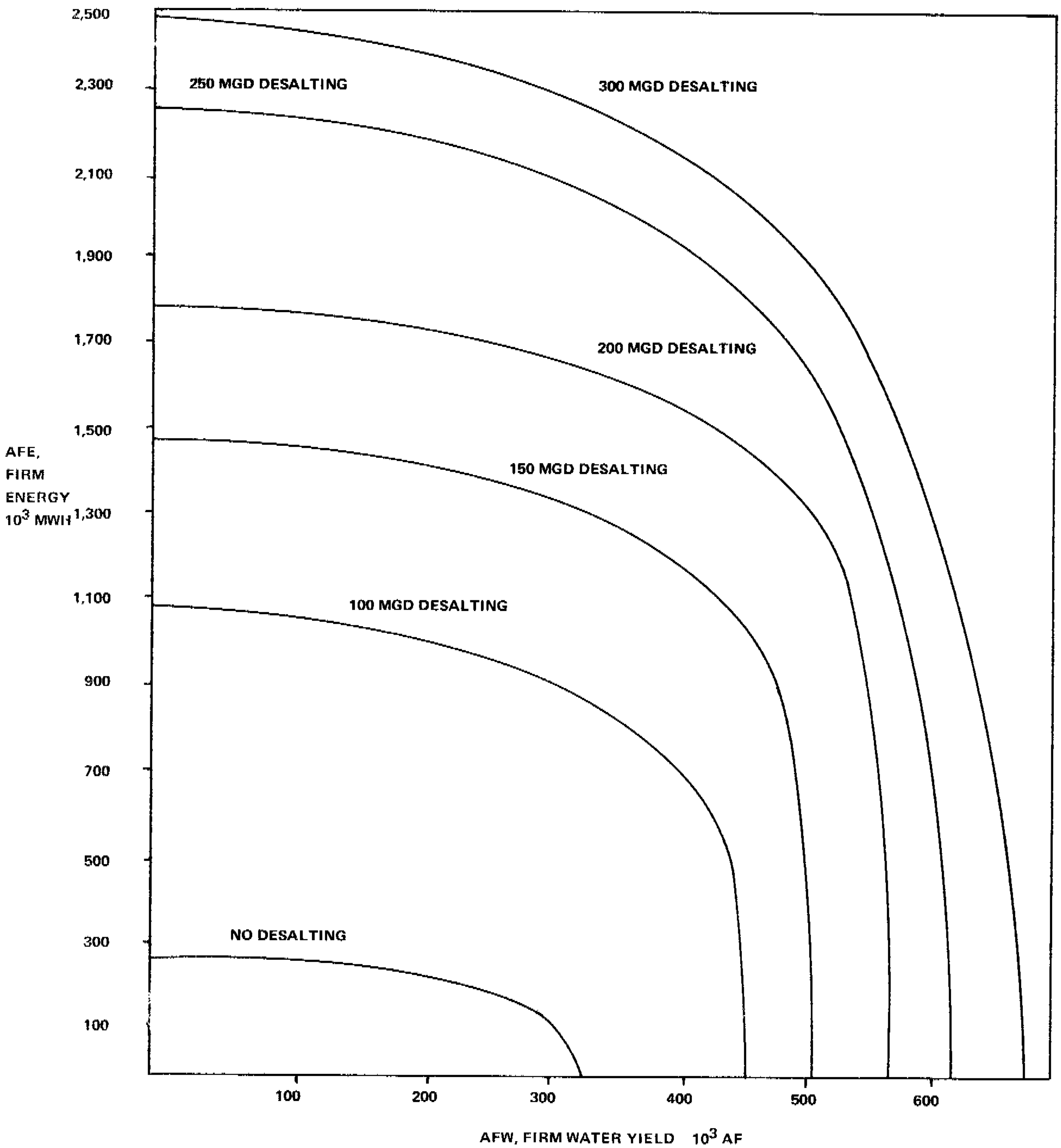


Figure 4.1 Production Possibility Curves ("No desalting" is Case A-1; others represent Case A-4)

over the simple reservoir system. Using firm on-peak energy and dump energy prices at \$6/MWH and \$1/MWH respectively, the annual benefit is calculated using Equations [3.3.4]. The unit cost of additional firm water is then computed from Equation [3.3.5]. These are given in Table 4.8.

Using the unit water costs computed in Table 4.8, a curve between the additional quantity of firm water yield (ΔAFW) and the unit water costs for the additional firm water supply, is drawn for each size of the desalting plant (Figure 4.2). From these, the optimal unit cost curve can be drawn as the envelope of the least unit costs.

The unit water costs obtained when the desalting plant is operated by itself are given in Table 4.4. Thus, annual costs for the firm supply of water can be obtained by knowing the annual firm water level. Thus, the annual cost for 67KAF of firm water is given by:

$$\text{Annual Cost} = \text{AFW} \times \text{UNCOST}$$

$$= 67 \times 131 \times 10^3 = 8.77 \times 10^6 \ \$$$

Similarly, from Table 4.6, the annual costs for additional water supply, when a desalting plant is operated with a small reservoir, can be obtained. The annual costs for conjunctive operation can be obtained from the least cost curve and the corresponding additional firm water as in Figure 4.2. The annual costs curves for additional firm water for all the 3 cases are shown in Figure 4.3.

4.6 Analysis of Reservoir System and Conjunctive System Under Altered Conditions. Case A5.

So far, water systems have been studied under given physical conditions, based on hydrological data. Often, however, it is desirable to know the behavior and response of the system when some of the input parameters are altered. This involves in essence a sensitivity analysis.

Computations are carried out for the cases when the stream inflows are more critical, less critical, and when reservoir sizes are made smaller. When stream inflows become more critical it is assumed that the inflow I_1 is affected, and decreases by 25%. Thus, lesser quantities of water flow into the system. Under less critical conditions, the inflows I_1 increase by 25% over those used originally (normal operation), and there is a greter quantity of water flowing through the system. When reservoir sizes are decreased, the storage capacity of the system is decreased. This is studied by decreasing the sizes and initial storage levels in reservoirs 1 and 3 by 25%.

The results of the computer runs for reservoir operation are given in Table 4.9 and production curves drawn from these results are in Figure 4.4. Table 4.10 gives the results from computations for conjunctive operation with a 100 MGD desalting plant, and the production curves for these cases are shown in Figure 4.4.

A comparison of operation of the surface reservoir system and conjunctive system is made in Table 4.11. The percentage improvement of firm water from conjunctive operation over that from reservoir operation is computed in each case, as also the cost of additional firm water supply. It is assumed that the desalting plants used are designed and operated at the same load factor as were determined in Case A4.

4.7 Parallel Reservoir System Operation. Case B1 and B2.

The effect of changing the reservoir system configuration can be studied by considering a parallel reservoir system. This configuration is shown in Figure 2.4. The physical parameters of the system, such as reservoir sizes, the inflows into the system, demands for water and power, etc., remain the same as before. However, in this case, demands P_3 and P_4 are external to the two branchs of the parallel system. As discussed in Section A.4, it is assumed that ΘP_3 is the portion of the demand P_3 which is satisfied from reservoir 1, and ρP_4 is the portion of the demand P_4 which is satisfied from reservoir 3. Thus $(1-\Theta)\ P_3$ will be satisfied from reservoir 1, and $(1-\rho)\ P_4$ from reservoir 3.

A unidimensional search is carried out over the feasible values of Θ and ρ, to determine the optimal combination which gives the maximum hydroelectric power output. Thus, from the simulation model, the maximum firm water level is determined. For this level of output, the electricity production for each of the 25 feasible combinations of θ and ρ values is computed from the dynamic programming model. The maximum electricity production is obtained when $\theta = .4$, and $\rho = .6$. These optimal values of θ and ρ are used for all further computations.

The computation results for a parallel reservoir system are given in Table 4.12. Computer runs are also made for conjunctive operation with a 100 MGD desalting plant (Table 4.12), and the respective production curves are drawn in Fig. 4.5.

The unit cost of additional firm water for the parallel case is computed as for Case A-4. Table 4.13 gives

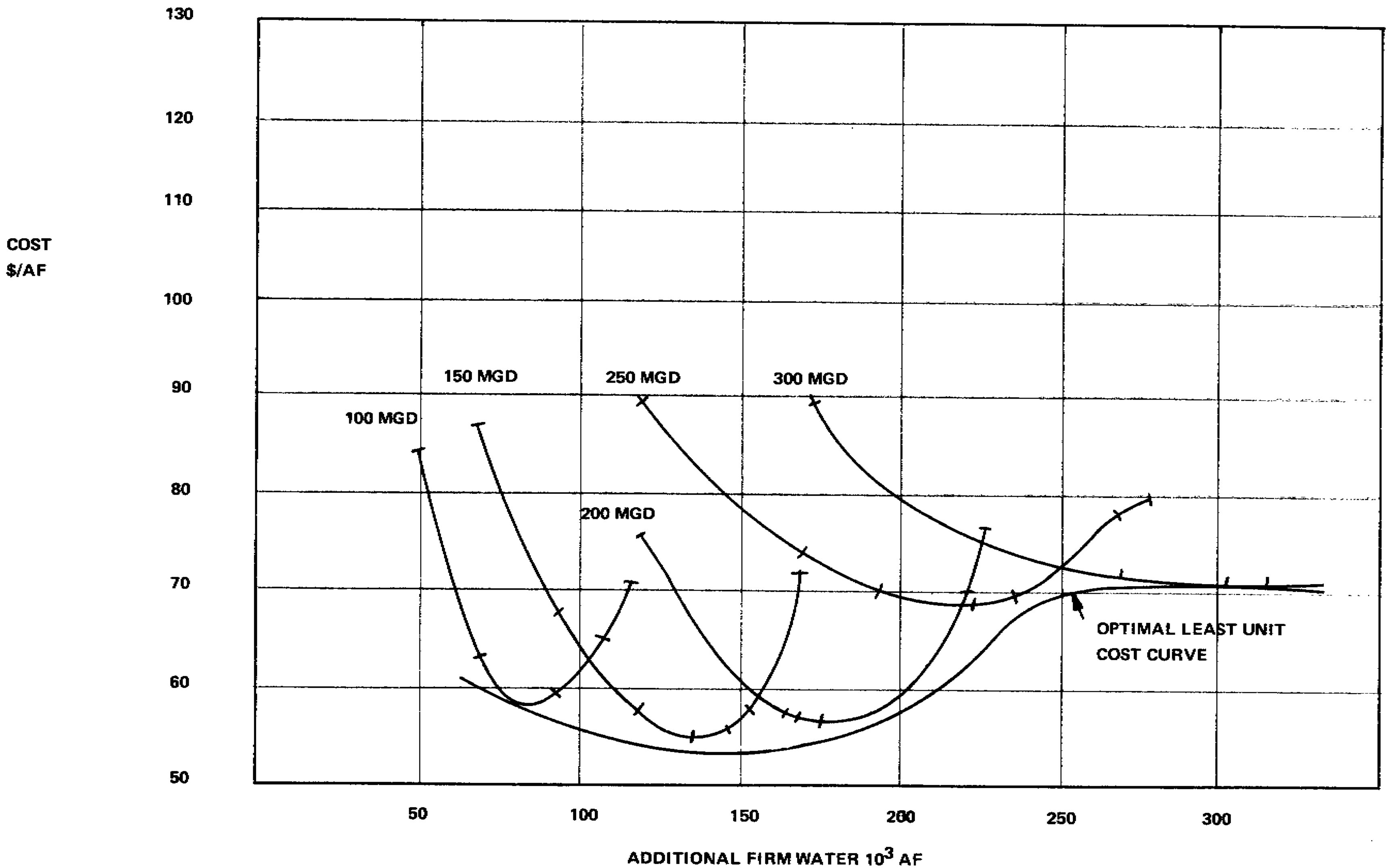


Figure 4.2 Unit Water Cost Curves From Conjunctive Operation

TABLE 4.8

CALCULATION OF UNIT COSTS FROM CONJUNCTIVE OPERATION

(Case A4)

AFW	=	Annual Firm Water
AFE	=	Annual Firm Energy
EVADE	=	Equivalent Annual Dump Energy
Δ	=	Increase In Variable
KAF	=	1000 Acre-Feet

AFW KAF	ΔAFW KAF	AFE 10^3MWH	EVADE 10^3MWH	ΔAFE 10^3MWH	ΔEVADE 10^3MWH	ANNUAL BENEFIT 10^3\$ $6/MWH ΔAFE	$1/MWH ΔEVADE	NET ANNUAL WATER COST 10^3\$	UNIT COSTS $/ AF	¢/10^3 GAL.
100 MGD Desalting Annual Cost (45.8%) = 9350 x 10^3 $										
445	112.5	242	1177	171	389	1029	389	7932	71	22
+*435	102.5	470	1090	399	302	2396	302	6652	65	20
425	92.5	680	1007	609	219	3656	219	5475	59	18
*412.5	80	810	1041	139	253	4436	253	4661	58	18
400	67.5	857	1076	786	288	4715	288	4347	64	20
*382.5	50	870	1078	799	290	4794	290	4266	85	26
*367.5	35	875	1080	804	292	4824	292	4234	121	37
150 MGD Desalting Annual Cost (49.5%) = 13860 x 10^3 $										
500	167.5	215	1698	144	910	864	910	12086	72	22
*487.5	155	750	1590	679	802	4076	802	8982	58	18
475	142.5	944	1499	873	711	5238	711	7911	56	17
*467.5	135	1025	1475	954	687	5724	687	7449	55	17
*450	117.5	1130	1440	1059	652	6354	652	6854	58	18
425	92.5	1229	1408	1158	620	6948	620	6292	68	21
400	67.5	1299	1338	1228	550	7368	550	5942	88	27

+Values marked with asterisk (*) are derived from curves drawn through calculated values.

TABLE 4.8 (Cont'd)

			200 MGD Desalting Annual Cost (56.6%) = 18800 x 10^3 $							
557.5	225	139	1950	68	1162	408	1162	17230	77	24
550	217.5	498	1850	427	1062	2564	1062	15174	70	21
*525	192.5	1245	1750	1174	962	7044	962	10794	56	17
*5.2.5	180	1429	1598	1358	810	8148	810	9842	55	17
*506.5	174	1480	1600	1409	812	8454	812	9534	55	17
500	167.5	1507	1600	1436	812	8616	812	9372	56	17
*450	117.5	1570	1620	1499	832	8994	832	8974	76	23
425	92.5	1600	1635	1529	847	9174	847	9779	95	29
			250 MGD Desalting Annual Cost (60%) = 23570 x 10^3 $							
612.5	280	136	1942	65	1154	390	1154	22026	79	24
*600	267.5	265	2368	194	1580	1164	1580	20826	78	24
567.5	235	1080	2200	1009	1412	6054	1412	16104	69	21
550	217.5	1310	2178	1239	1390	7434	1390	14746	68	21
*525	192.5	1495	2303	1424	1515	8544	1515	13511	70	21
450	117.5	2037	1995	1966	1207	11796	1207	10567	90	28
			300 MGD Desalting Annual Cost (60%) = 28000 x 10^3 $							
667.5	335	602	1959	531	1171	3186	1171	23653	71	22
*650	317.5	750	2218	679	1430	4074	1430	22496	71	22
*63 .5	300	915	2350	844	1562	5064	1562	21374	71	22
*600	267.5	1250	2470	1179	1682	7074	1682	19244	72	22
550	217.5	1713	2307	1642	1519	9852	1519	16629	76	23
*532.5	200	1815	2350	1744	1562	10464	1562	15974	80	25
500	167.5	1978	2406	1907	1618	11442	1618	14940	89	27

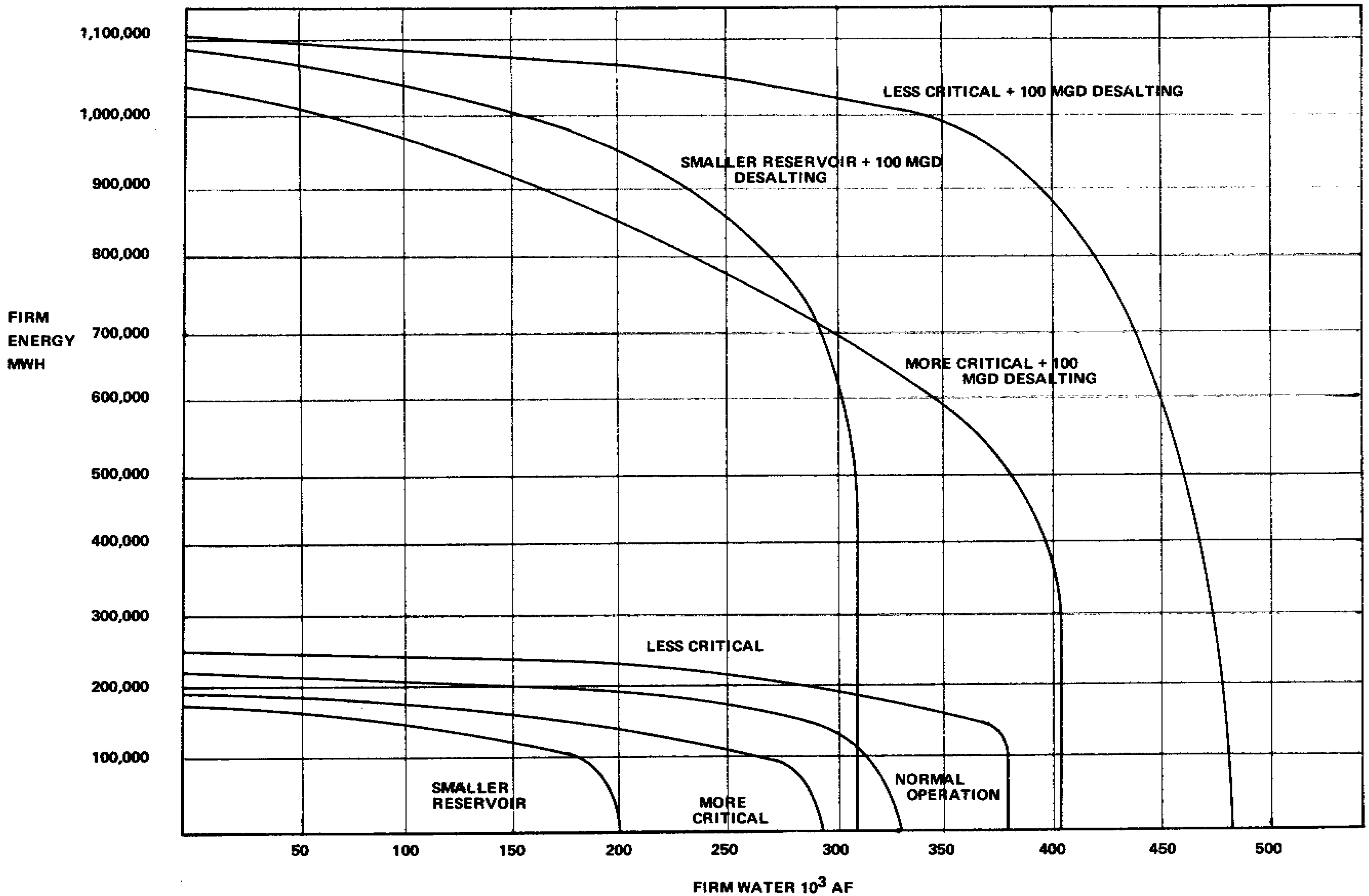


Figure 4.4 Production Possibility Curves for Altered Conditions

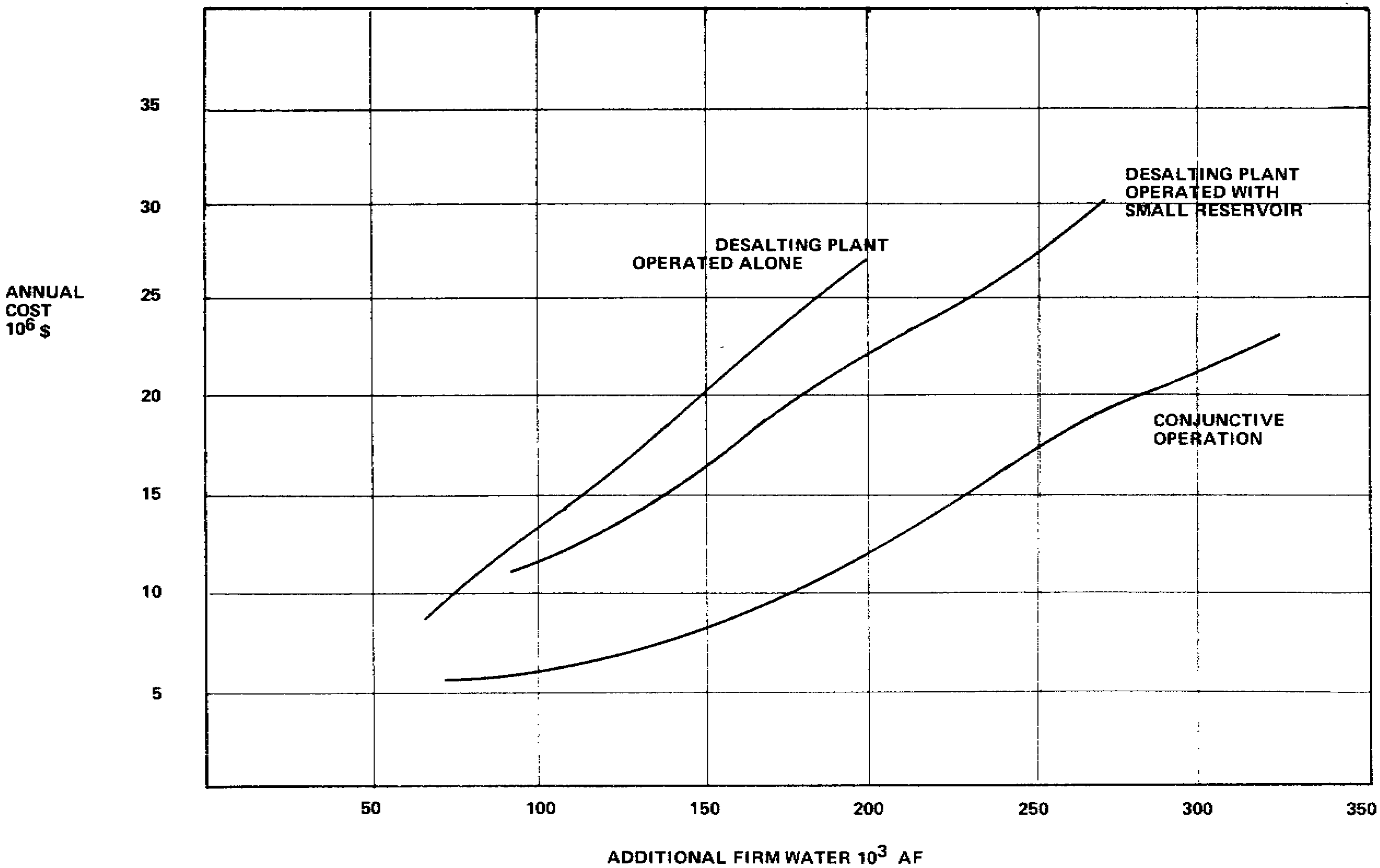


Figure 4.3 Annual Water Costs for Additional Firm Water

the results of these computations. Again, the desalting plant costs are based on the optimum design and operating load factor.

TABLE 4.9

RESULTS FROM COMPUTATION RUNS FOR RESERVOIR OPERATION

(Case A5)

System Configuration	AFW KAF	AFE 10^3 MWH	EVADE 10^3 MWH
Normal Condition (Same as in Table 4.1)	332.5	71	232
	300	128	195
	200	201	164
	100	222	88
	0	228	70
More Critical Inflow Conditions	295	98	180
	200	120	166
	100	174	135
	0	194	100
Less Critical Inflow Conditions	370	173	135
	300	186	123
	200	226	98
	100	245	73
	0	252	67
Smaller Reservoirs	205	99	183
	175	96	183
	100	169	136
	0	186	95

TABLE 4.10

COMPUTATIONAL RESULTS FOR CONJUNCTIVE

OPERATION WITH 100MGD DESALTING

(Case A5)

System Configuration	AFW KAF	AFE 10^3 MWH	EVADE 10^3 MWH
Conjunctive Operation with Normal Condition (Same as in Table 4.7)	445	242	1117
	425	680	1007
	400	857	1076
	345	882	1126
	320	885	1153
	175	995	1086
	0	1098	1020
Conjunctive Operation with More Critical Inflows	407.5	445	1117
	375	326	1207
	200	865	1178
	100	942	1141
	0	1034	1117
Conjunctive Operation with Less Critical Inflows	482.5	858	1057
	450	870	1064
	300	948	1104
	150	1070	998
	0	1111	997
Conjunctive Operation with Smaller Reservoirs	317.5	836	1040
	300	854	1040
	150	915	1096
	0	1097	1038

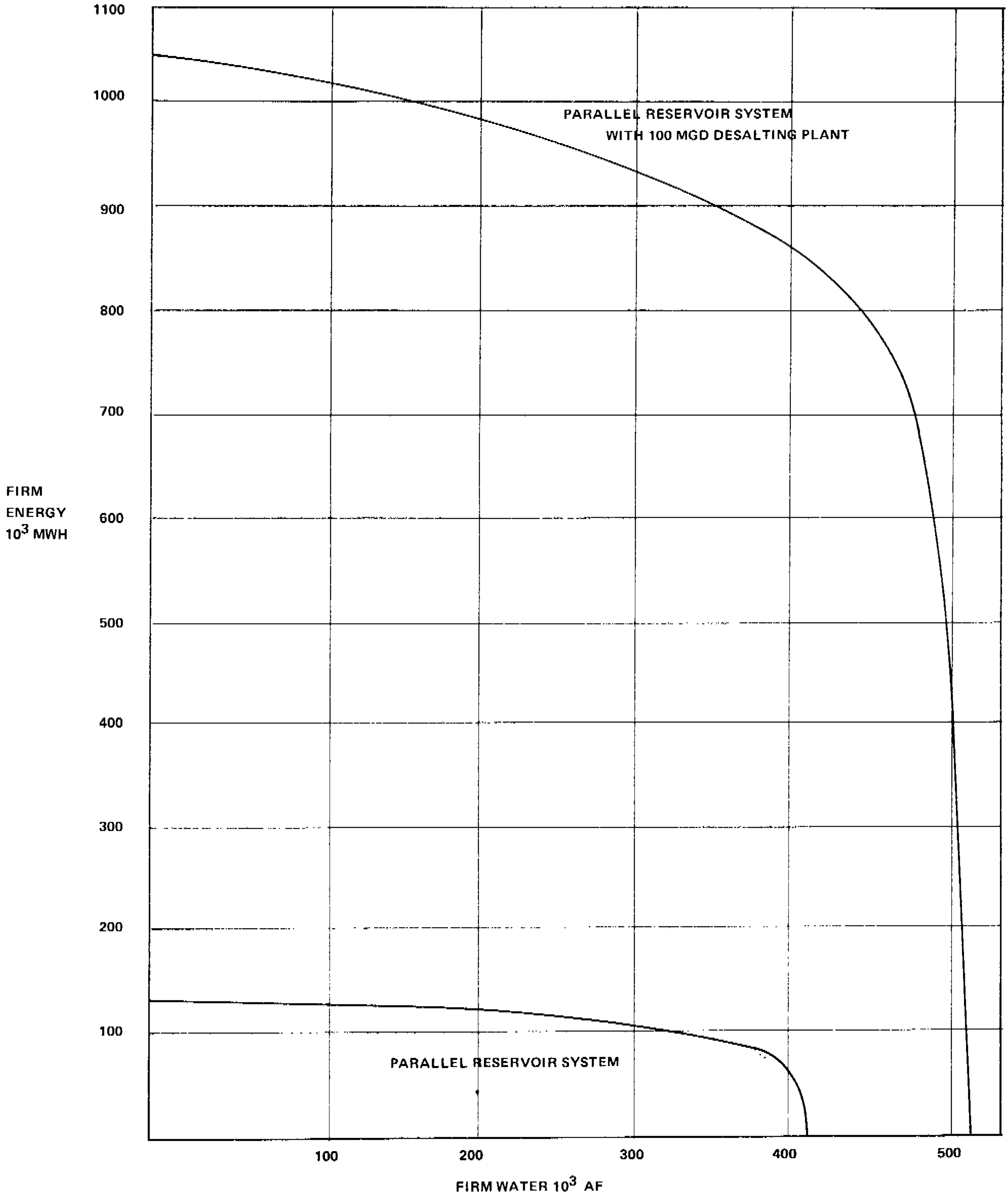


Figure 4.5 Production Possibility Curves for Parallel Case

TABLE 4.11

COMPARISON OF SURFACE & CONJUNCTIVE SYSTEMS UNDER DIFFERENT OPERATING CONDITIONS

(100 MGD Desalting Capacity)

	NORMAL OPERATION		MORE CRITICAL OPERATION		LESS CRITICAL OPERATION		OPERATION WITH SMALLER RESERVOIRS	
	Surface System	Conjunctive System	Surface System	Conjunctive System	Surface System	Conjunctive System	Surface System	Conjunctive System
1. AFW KAF*	332.5	445	295.0	407.5	370.0	482.5	205.0	317.5
2. AFE 10^3MWH	71	242	98	445	173	858	99	836
3. EVADE 10^3MWH	232	1177	180	1117	135	1057	183	1040
4. ΔAFW KAF		112.5		112.5		112.5		112.5
5. ΔAFE 10^3MWH		171		347		685		737
6. ADE_{DES} 10^3 MWH		556		556		556		556
7. $\Delta EVADE = EVADE_C - EVADE_R - ADE_{DES}$ 10^3MWH		389		381		366		301
8. % Increase in AFW = $\frac{\Delta AFW}{AFW_{RES}}$		33.8%		33.1%		30.4%		54.9%
9. Annual Benefit from ΔAFE at \$6/MWH in 10^3\$		1026		2082		4110		4422
10. Annual Benefit from ΔEVADE at \$1/MWH in 10^3\$		389		381		366		301
11. Annual Cost of Desalting Plant at Designed Load Factor in 10^3\$ (45.8%)		9350		9350		9350		9350
12. Net Annual Water Costs 10^3\$		7935		6887		4874		4627
13. Cost \$/AF of Additional Water		71		61		43		41
14. Cost ¢/1000 Gal. of Additional Water		22		19		13		13

*AFW = Annual Firm Water, KAF = 1000 Acre Feet, AFE = Annual Firm Energy, EVADE = Equivalent Annual Dump Energy, Δ = Increase in Variable, ADE_{DES} = Annual Dump Energy from Desalting Plant.

COMPUTATIONAL RESULTS FOR

PARALLEL RESERVOIR SYSTEM

AFW KAF	AFE 10^3MWH	EVADE 10^3MWH
Without Desalting		
410	50	108
350	69	83
300	81	75
200	110	48
100	122	39
0	133	30
With 100 MGD Desalting Plant		
520	58	692
450	837	890
400	857	961
300	893	977
200	963	973
100	1001	971
0	1050	1030

TABLE 4.13

ANALYSIS OF PARALLEL RESERVOIR SYSTEM

100 MGD Desalting

Max P_4 = 410KAF+
AFE = 50,210MWH
EVADE = 108,392MWH
DE_{DES} = 556,000MWH
TOTAL DE = 664,392MWH

Annual Cost of Plant = 9350 x 10^3\$

						ANNUAL BENEFIT 10^3\$		ANNUAL WATER COST BENEFIT	UNIT COSTS	
AFW+ KAF	ΔAFW KAF	AFE 10^3MWH	EVADE 10^3MWH	ΔAFE 10^3MWH	ΔEVADE 10^3MWH	\$6/MWH ΔAFE	\$1/MWH ΔEVADE	10^3\$	\$/ AF	¢/1000 Gal.
520	187.5	58	692	8	28	48	28	9274	49	15
*500	167.5	560	750	510	86	3060	86	6204	37	11
*467.5	135	785	800	735	136	4410	136	4804	36	11
450	117.5	837	890	787	226	4722	226	4402	37	11
400	67.5	858	961	808	297	4848	297	4205	62	19

* From Curve Fitting.

+ P_4 is Terminal Water Demand, KAF = 1000 Acre-Feet, AFE = Annual Firm Energy, EVADE is Equivalent Annual Dump Energy, DE = Dump Energy, DES Signifies Desalting, AFW is Annual Firm Water, Δ Denotes Increment in Variable.

CHAPTER 5

CONCLUSIONS AND RESULTS

This study tests, for a hypothetical but realistic example, the economic advantages to be gained by using dual-purpose desalting plants in conjunction with multi-purpose reservoirs, for meeting the water and power requirements of a region. The conjunctive operation, as shown, for a system of reservoirs in series in Figure 4.1 and Table 4.8, in comparison to an independent operation of reservoirs and a desalting plant:

1. Increases the annual firm water yield, and thus the capacity of the system. (See the ΔAFW column in Table 4.8

2. Increases the annual firm and dump energy supplies. (See the ΔAFE and ΔEVADE columns in Table 4.8)

3. Improves the overall reliability of the system, by providing reserve capacity.

The unit cost of additional amounts of firm water is considerably less for conjunctive operation, for this hypothetical example. The percentage savings are shown in the Conclusions section at the beginning of the report; they are on the order of 50%. Thus, an inexpensive source of firm water becomes available as a result of conjunctive operation. (See Figure 4.3 and compare the last columns of Tables 4.4, 4.6, and 4.8.)

When the system is operating under more critical conditions, that is, when the water that might become available from reservoirs is less because of stream flow conditions or smaller reservoirs, the overall operation of the conjunctive system becomes more valuable. Although the incremental firm yield for each of the cases cited in quite similar in absolute terms, the percentage increase in yield is noticeably different. When a 100 MGD desalting plant is operated together with a series reservoir system, the maximum firm water yield increases from 332 KAF for reservoir system to 445 KAF, an increase of about 34%. When the stream flow conditions are more critical, the firm water increases from 295 KAF to 407 KAF, an increase of 40%; for less critical conditions, the firm water increases from 370 KAF to 482 KAF, an increase of 30%. When reservoir size is smaller, firm water increases from 205 KAF to 317 KAF, an increase of 52%. Thus, with the same size of desalting plant, the yield from the conjunctive system becomes considerably better as the hydrological conditions become more critical.

The firm energy production decreases considerably when the analysis is carried out with a parallel reservoir system. The maximum firm water output of the parallel reservoir system is 410 KAF, as compared to 332 KAF for the series reservoir system, an increase of 23%, but the corresponding firm energy production falls from 71 x 10^3MWH to 50 x 10^3MWH, a decrease of 30%. When the reservoir systems are operated conjunctively with a 100 MGD desalting plant, the maximum firm water production with a parallel reservoir system is 520 KAF, against 445 KAF with a series reservoir system, an increase of 17%, but the corresponding firm energy production falls from 242 x 10^3MWH to 58 MWH, a decrease of 76%. Thus, under the parameters assumed, it is more beneficial to have conjunctive operation with a parallel reservoir than with a series system, if greater firm water outputs are required. But the energy production is expected to decline because of the decrease in the quantity of water which flows through reservoirs.

5.1 Limitations of the Model

The system is very sensitive to operation near the maximum firm water yield. The simulation model developed, therefore, has the limitation as a computational method that it does not give optimal solution in computer runs. This disadvantage, however, is not of major consequence, since production possibility curves are developed by the dynamic programming procedure. And near the point of maximum firm water yield, there is a large shift in the production curve, and firm energy production increases substantially for small changes in firm water. This phenomenon enables one to carry out a relatively easy economic analysis to determine the optimum point.

The incremental dynamic programming algorithm is based on iterations of state variables. Due to the cost of compution there is a restriction on the number of iterations. In all computer runs for this study, 35 iterations were used. This is an arbitrary number chosen in practice, on the basis of preliminary runs. This arbitrativeness is necessary because it is a complicated task to set up a criterion where the algorithm terminates iterating when it is "sufficiently" close to the optimal.

The entire analysis has been carried out on the basis of the critical hydrological period. Conjunctive operation increases the safe yield of the system, based on these historical data. However, the model has the drawback that it does not give monthly operational policies. Instead, it provides a long-term operation strategy, i.e., firm contract levels. Clyde and Blood's analysis used simulation modeling (Reference 8). For such a calculation, however, a stochastic-probabilistic model has to be developed, which takes into account the uncertainty of the future quantity of inflow into the reservoirs over time. The present model is more in the nature of a long range predictive model, which determines the general system characteristics, but does not get into specific operating policies after the construction of the desalting plant. Operating policy must be determined, in most cases, on very short time intervals, i.e., hourly releases from the reservoirs, and any model which attempts to incorporate all the basic parameters to operate such a system becomes too complex to be of any practical value anyway.

5.2 Use of the Models in Actual Cases

These models can be used to make planning decisions. Thus, using Fig. 4.1, 4.2, and 4.3 (see Fig. 5.1), questions relating to the type of conjunctive operation for different conditions can be answered. This is illustrated by an example:

Problem: To increase the firm water yield of the existing system by x KAF (x = 200 KAF for this example), at a minimum cost.

From Fig 5.1 a, the annual cost of 200 KAF of firm water can be read off for three cases: when a desalting plant is operated alone, operated with a small reservoir, and when we have conjunctive operation. The least cost is obviously for conjunctive operation, and equals $\$11.2 \times 10^6$ per year. This cost may be compared with the cost of other alternatives, such as additional reservoir constructions, water importation from other regions, waste reclamation, etc.

Corresponding to 200 KAF of additional firm water, Fig 5.1 b gives the minimum unit cost of water (from the envelope), at this level of supply. Also, the figure reveals the optimum desalting plant size which gives this unit cost, in this case 200 MGD.

The load factor for the desalting plant size obtained above is known from the computer runs made to develop this envelope, and thus the plant can be designed at that load factor, in this case 56.6%.

From the production possibility curves in Fig. 5.1 c, corresponding to conjunctive operation with a 200 MGD desalting plant, the firm energy contract levels and dump energy productions are also determined.

Thus, for a specified level of additional firm water supply under the given system configuration, the following can be determined from the type of hydrological records indicated in detail in Appendix B:

1. Minimum Annual Cost of additional firm water.

2. Minimum Unit Cost of additional firm water.

3. Desalting plant size and load factor for the desalting plant to provide the additional water supply at the minimum cost.

4. The firm energy contract level for the system.

5. Dump energy production for the system.

5.3 General Discussion

The optimal cost curve developed in Fig. 4.2, is sensitive to desalting plant size between the values 200 MGD and 250 MGD. This may possibly have something to do with details of the configuration of the system, such as reservoir sizes, which cause a sensitive shift in costs for conjunctive operation in this critical range.

The results from computer models are independent of price. The models determine the output levels of firm water, firm energy, and dump energy. An economic model is then used to calculate the benefits. Thus, even if the prices change, as is often the case, the computer runs are still valid, and simple computations with a desk calculator will establish the benefits derived.

The desalting plant configuration assumed for this analysis, may change in another situation. However, this will only change the desalting plant and nuclear fossil-fueled power plant capacities, and the associated costs. The plant capacities can be changed very simply in the input data cards, and the cost variations are taken care of in the economic analysis. Thus, even if desalting technologies change, the model remains valid.

The input data used for the model are the historical hydrological data for a watershed, in terms of inflows, evaporation rates, reservoir characteristics, etc. (For most purposes, the tracing of drought periods for critical flow can be accomplished from inflow data sufficient to display a typical wet-dry cycle, e.g., ten years.) Any or all of these data can be changed in the input data cards. Hydrological data is usually available from water resource agencies, and thus the application of the model does not require extensive data collection, but can make use of data already available.

The models developed in this study are general

Figure 5.1a Annual Water Costs

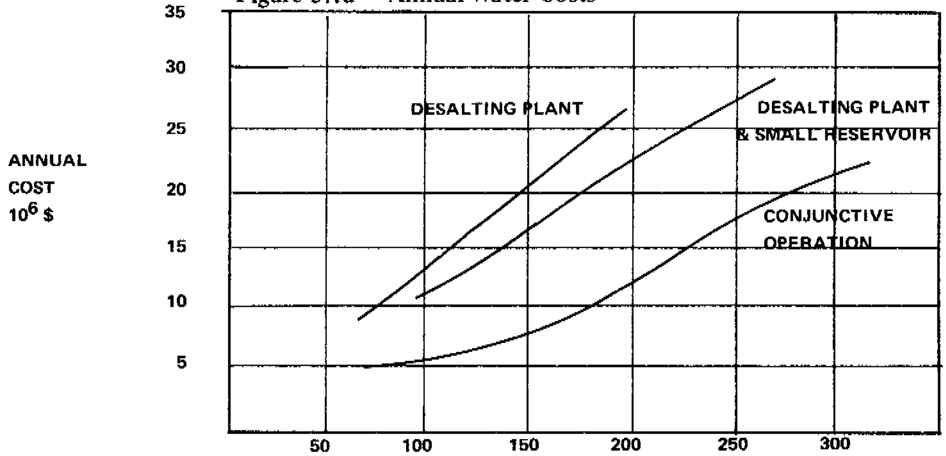


Figure 5.1b Unit Water Costs

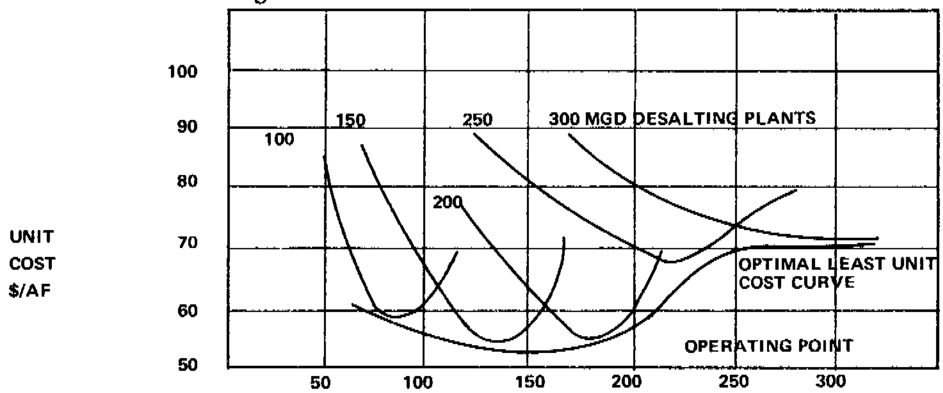
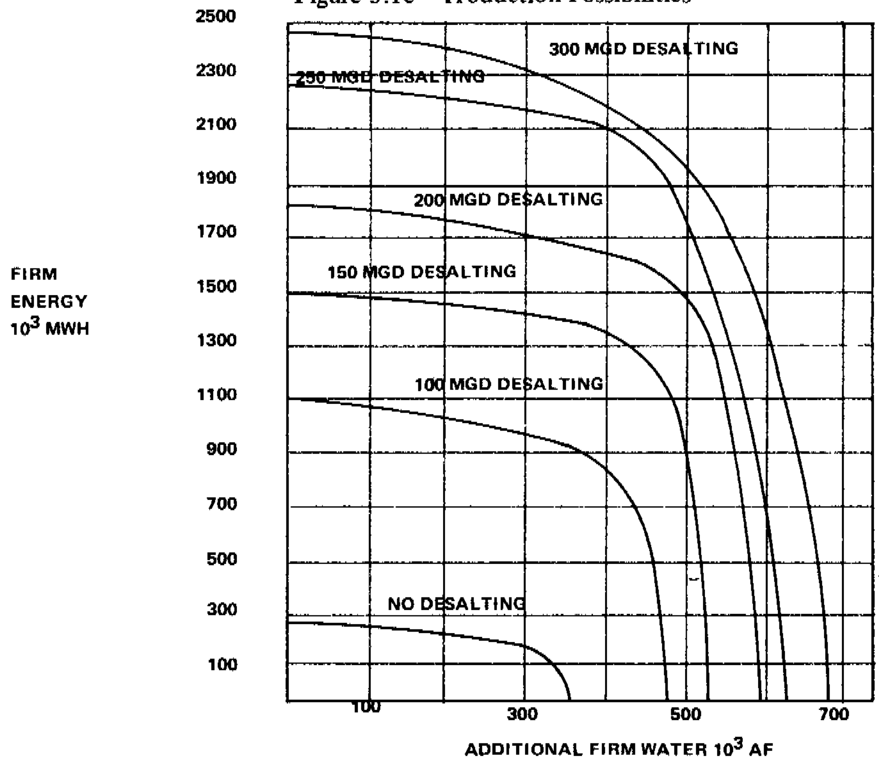


Figure 5.1c Production Possibilities



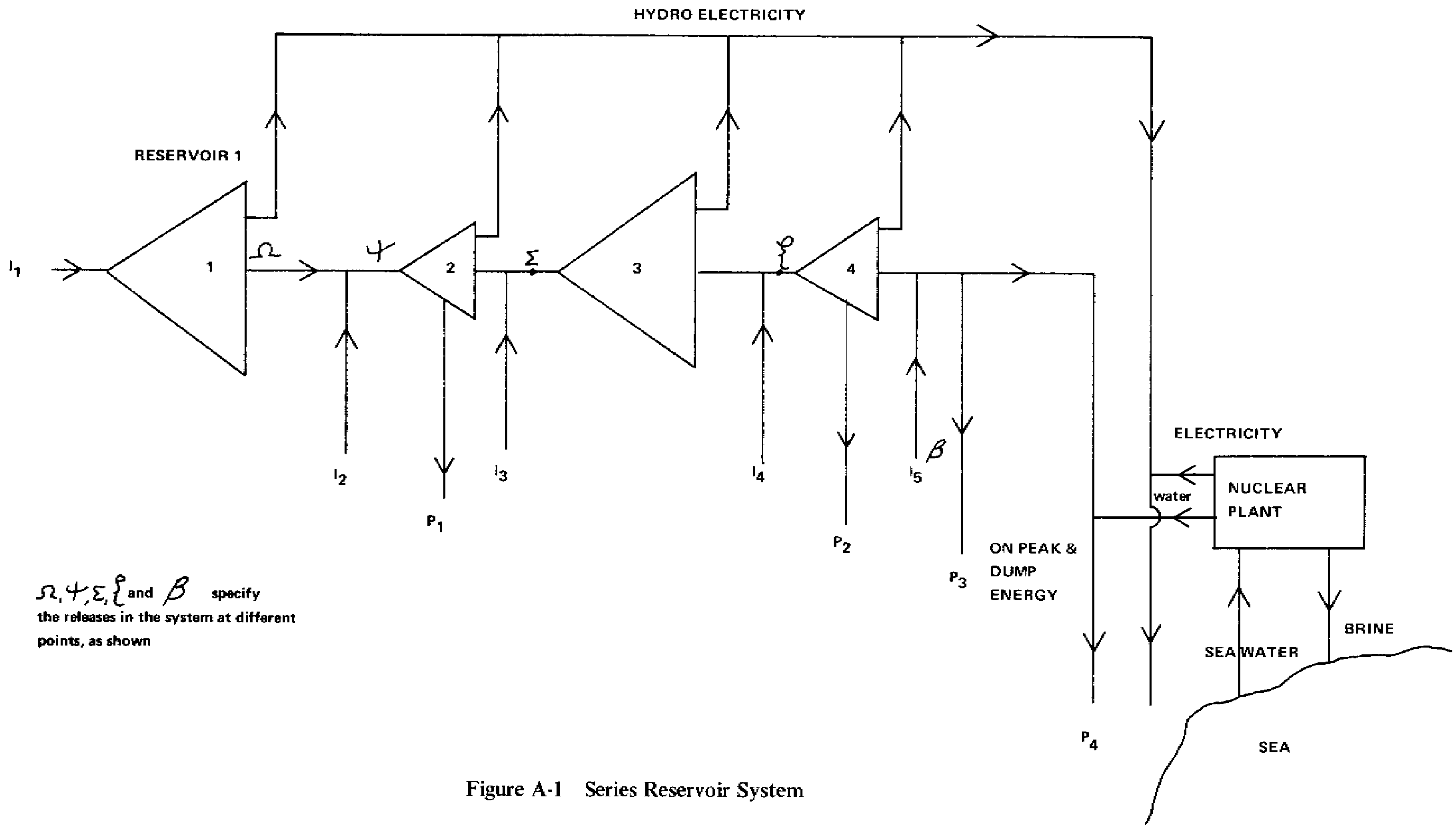


Figure A-1 Series Reservoir System

insofar as they can be adapted to similar systems without many changes in computational procedure. Any series, four-reservoir system which can be described in physical parameters, similar to the present configuration, can be handled. To use the computer routine for a five- or six-reservoir, or some other system configuration, however, modifications will be necessary. The logic of the computation remains the same, but the number of state and decision variables will increase, and hence the setup of the computer program will change.

APPENDIX A

FORMULATION OF MATHEMATICAL MODELS

The following is the notation used in formulation of the mathematic models in this chapter.

AFW	=	Annual firm water supply.
AFE	=	Annual firm energy supply.
b_n	=	Amount of desalinized water produced by each unit in period n.
$C_i(S, R^t)$	=	Capacity of hydroelectric plant i as a function of storage level S and release through turbine R^t. i = 1 or 3.
$C_5(Wn)$	=	Net generation capacity of nuclear power plant as a function of the number of desalting units in operation.
DE(n)	=	Total dump energy in period n.
D_{in}	=	Amount of water in storage in reservoir i at the beginning of period n. i = 1, 3.
$e_{in}(S_{in}, D_{in})$	=	evaporation from reservoir i in period n as a function of storage levels at beginning and end of period. i = 1, 2, 3, 4.
$f_n\ (S_{in}, S_{3n})$	=	Optimum return from the first period of operation up to period n, following an optimal policy for the reservoirs and the dual-purpose desalination plant.
e_{in}	=	evaporation from reservoir i in period n. i = 1, 2, 3, 4.
ER_{in}	=	evaporation rate from reservoir i in period n. i = 1, 2, 3, 4.
γ_i	=	evaporation rate conversion factor for reservoir i. i = 1, 2, 3, 4.
$h_i(S)$	=	Energy production rate in power plant i per unit of release at storage level S. i = 1, 2, 3, 4.
I_{in}	=	Inflow to reservoir i during period n. i = 1, 2, 3, 4, 5.

m	=	Number of desalination units or multistage flash distillation plants.
OPH_n	=	On peak hours in period n.
OPMAX	=	Parameter slightly smaller than maximum storage level in reservoir 3. Used to prevent round-off errors in computation.
P_{in}	=	Demand (i = 1, 2, 3, 4) during period n.
R_{in}	=	Total release from reservoir i during period n. i = 1, 2, 3, 4.
$R_{in}t$	=	Release through turbine hydro power plant i during period n.
S_{in}	=	Water storage in reservoir i at end of period n. i = 1, 2, 3, 4.
U_{in}	=	On peak energy production by reservoir i during period n. i = 1, 2, 3, 4.
U_{sn}	=	On peak energy from desalting plant.
SiMIN (n)	=	Minimum storage in reservoir i (i = 1, 2, 3, 4) in period n.
SiDEAD	=	Dead storage level in reservoir i. i = 1, 2, 3, 4.
SiINIT	=	Initial storage level in reservoir i. i = 1, 2, 3, 4.
TH_n	=	Total hours available for production in period n.

A.1 Series Reservoir System and Dual Purpose Desalting Plant

A river basin is likely to have a series of multipurpose surface reservoirs to satisfy the regional water and some portion of the power requirements. A dual purpose desalting plant can be linked on to such a system to "firm up" the water and energy. A general 4 reservoir system with a desalting plant can thus be represented as shown in Figure A-1.

This simplified representation of the conjunctive system includes general demands for municipal, industrial, and irrigation water supplies, as indicated by P_1, P_2, P_3, and

P_4, at different points. Inflows from the main river and tributories are represented by I_1, I_2, I_3, I_4 and I_5. Two of the reservoirs (1 and 3) are multipurpose large storage reservoir with variable water level and the other two (2 and 4) are constant head reservoirs. Every dam has a hydropower plant with fixed installed capacity. When the operation of the dual purpose desalting plant is linked into the surface reservoir system, optimal operation of the conjunctive system implies:

(1) All the upstream water demands must be satisfied for the period of analysis.

(2) There are storage constraints on the system because the flood control objectives must be satisfied.

(3) The firm on-peak electricity production must be maximized while the specified level of water demand in the zone near the coast, i.e., P_4, is satisfied by releases from reservoirs and product water from the desalting plant.

Changing the water demand P_4 will have an effect on the level of firm on-peak electricity production. To find the optimum contract level for these two products the production tradeoff between these two firm outputs must be known. In other words, a "production possibility curve" for the conjunctive system must be developed. The total mathematical model used for the development of this curve has two submodels: (1) a simulation model, (2) an incremental dynamic programming model.

A.2 The Simulation Model

The main reasons for the development of the simulation model are:

(1) To make sure that upstream water requirements are satisfied without the storage levels in the reservoirs going below their minimum preassigned storage levels.

(2) To determine an initial policy for reservoir storages so that this initial policy can become an input into the incremental dynamic programming model.

(3) To determine the maximum water supply level when power production is not an objective.

The dynamic programming model subsequently starts modifying this initial policy, produced by the simulation model, by making incremental adjustments till an optimum policy is determined.

The basic equations used in simulation model are based on mass balance relations. The physical parameters of the reservoirs fix the minimum and maximum storage in each reservoir at any time. The inflows into the system are known, and it is assumed that P_1, P_2, and P_3 are known firm water commitments which must be met. Thus, knowing the fixed demands, evaporation losses, and the inflows, the minimum storage levels in reservoirs (1) and (3) necessary to meet the requirements in every period can be calculated by a backward recursive relationship (backward because the final demands are known, and we back calculate to determine the required storage levels). The equations used are:

$$\begin{aligned} \text{S3MIN}(n) = \; & \max \{ \text{S3DEAD}, \min [\text{S3MIN}(n+1), \text{OPMAX}] - I_{3n} \\ & + e_{3n}(S, D) - \min [(I_{4n} + I_{5n} - P_{2n} - P_{3n} \\ & \quad - e_{4n}), 0.0] \\ & - \max [(I_{2n} - P_{1n} - e_{2n}), 0.0] \} \end{aligned} \tag{A-1}$$

and

$$\begin{aligned} \text{S1MIN}(n) = \; & \max \{ \text{S1DEAD}, \min [\text{S1MIN}(n+1), \text{OPMAX}] - I_{1n} \\ & + e_{1n}(S, D) - \min [(I_{2n} - P_{1n} - e_{2n}), 0.0] \} \end{aligned} \tag{A-2}$$

Where

S1MIN (n MONTH + 1) = S1INIT = Initial Storage in Reservoir 1

S3MIN (n MONTH + 1) = S3INIT = Initial Storage in Reservoir 3

Thus, the minimum storage in any period for reservoirs 1 and 3 can be calculated. This level cannot fall below the dead storage level. Thus, the minimum storage will equal the dead storage level or the actual level in the resrvoir, determined from inflows and outflows in the period, whichever is greater.

Equations (A-1) and (A-2) specify the minimum storage in reservoirs (1) and (3) to meet all requirements up to P_3. Now, in actual operation, if the system fails to meet the firm water requirements, it will be because of P_4 being excessive. Thus the failure of the system will correspond to the maximum firm water demand P_4.

To determine MAXP4, the downstream demands are increased in steps. For each increase in P_4, extra water is first released from reservoir 1, until the level reaches S1MIN as determined by equation (A-1). Further increases in P_4 are met by releases from reservoir 3. In this way, a point is reached where an increase in P_4 will cause the level in reservoir 1 or 3 or both to fall below the minimum storage levels computed by equations (A-1) and (A-2). If desalting is to be used, then P_4 is first reduced by the full capacity of the desalting plant, then the increased downstream requirements are met as before.

The releases necessary to meet all the downstream requirements for the initial policy can be calculated from the following equations:

$$\beta = \max (P_{4n} - DW_n^*, 0) \tag{A-3}$$

$$\xi = \max (\beta + P_{3n} - I_{5n}, 0) + P_{2n} + e_{4n} \tag{A-4}$$

$$\varepsilon = \max (\xi - I_{4n}, 0) + e_{3n} \tag{A-5}$$

$$\psi = \max (\varepsilon - I_{3n}, 0) + P_{1n} + e_{2n} \tag{A-6}$$

$$\Omega = \max (\psi - I_{2n}, 0) \tag{A-7}$$

Assuming $S_3{}^*{}_n = S_3{}^*{}_{n-1}$

$$R_{1n} = \Omega$$

The above equations form a backward recursive relation. Thus, to meet the demand P_{4n} in period n (refer to Fig. A-1), the flow β must be sufficient to meet the excess of demand over what is available from the desalting plant DW_n^* (equation A-3). Similarly, ξ must satisfy the demand P_{3n}, the requirements for evaporation, the demand P_{2n}. There is an inflow into the system of I_{5n}. Thus, release is obtained from equation A-4. In the same way, mass balance equations give the releases at all points in the system--equation A-3 to A-7.

Now if a level of P_4 is given, then the model set-up will meet this requirement in every period by the operating rule specified, and thus the storage levels of reservoirs 1 and 3 and the releases can be calculated. This is referred to as the "initial policy." Monthly release and storage data obtained from the initial policy can then be used to calculate the production of electricity from the hydroplants and the turbogenerators of the desalting plant. This is done in the incremental dynamic programming model. The logic of the simulation model is shown in Figure A-2.

A.3 Incremental Dynamic Programming Model

The production of energy from the reservoirs will depend on the storage level and the release in any time interval. From the simulation model, the initial policy and hence the storage levels are known. The maximum on-peak energy production, for a given level or water supply is calculated by setting up a physical recursive relation to be solved by an incremental dynamic programming model. This model uses the result from the simulation model as the initial policy.

For the system under investigation, the model has two state variables, namely the amount of water stored in each of the two reservoirs at the end of every time period. There are three decision variables, the amounts of water stored in each of the reservoirs 1 and 3 at the beginning of every time period, and the desalination units operating in each time period. This will completely determine the net power which can be generated. The recursive relation for maximum on-peak firm energy is:

$$f_n\,(S_{1n},\,S_{3n}) \;=\; \max_{D_{1n},\,D_{3n},}\;\min_{W_n}\;\Big[\Big(\sum_{i-1}^{5} U_{in}/\alpha_n\Big),\; f_n\,(S_{,n-1},\,S_{3,n-1})\Big] \tag{A-8}$$

Where

$$S_{1\ n-1} = D_{1n}\;;\;S_{3\ n-1} = D_{3n}$$

The releases from the reservoirs are given by:

$$R_{1n} = D_{1n} + I_{1n} - S_{1n} - e_{1n}\,(S_{1n},\,D_{1n}) \tag{A-9}$$

$$R_{2n} = R_{1n} + I_{2n} - P_{1n} - e_{2n} \tag{A-10}$$

$$R_{3n} = D_{3n} + I_{3n} + R_{2n} - S_{3n} - e_{3n}\,(S_{3n},\,D_{3n}) \tag{A-11}$$

$$R_{4n} = R_{3n} + I_{4n} - P_{2n} - e_{4n} \tag{A-12}$$

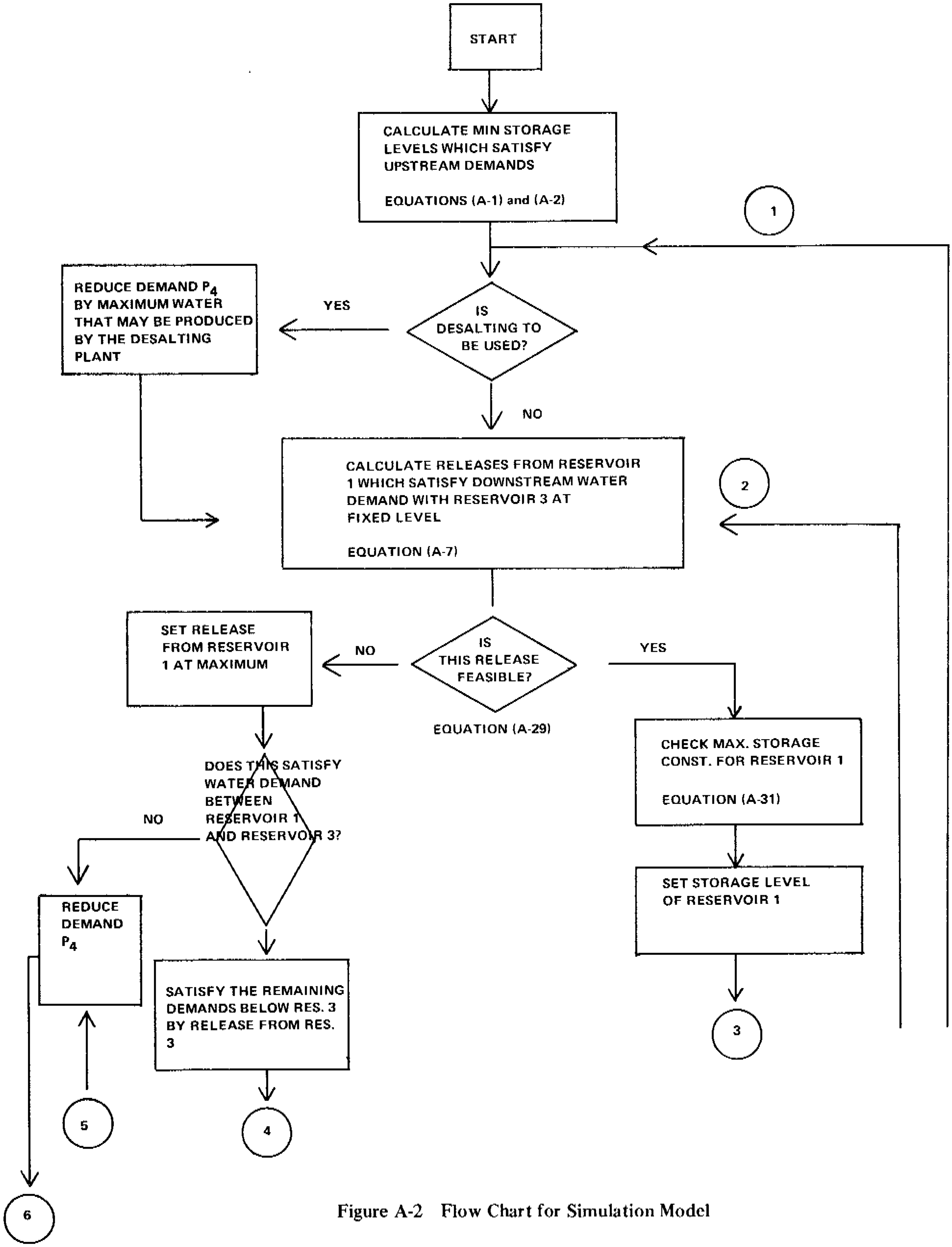
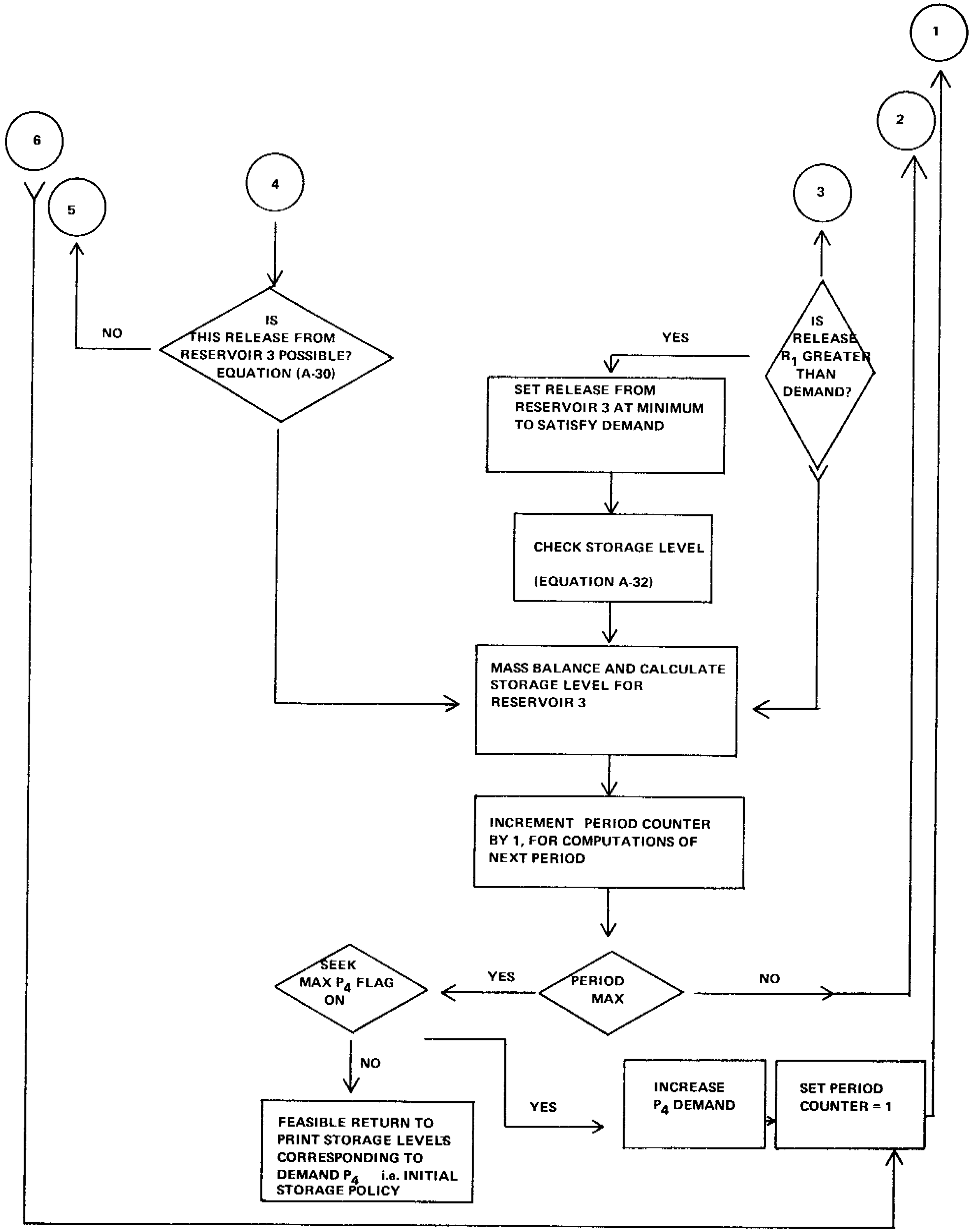


Figure A-2 Flow Chart for Simulation Model



Flow Chart for Simulation Model (con't)

The desalinized water production is given by:

$$DW_n = b_n . W_n \qquad \text{(A-13)}$$

The evaporation losses from the reservoirs will depend on the surface area of the reservoirs, and can be represented mathematically as:

$$e_{1n} (S_{1n}, D_{1n}) = ER_{1n}\ \gamma_1\ (1/2\ S_{1n} + 1/2\ D_{1n}) \qquad \text{(A-14)}$$

$$e_{2n} = ER_{2n} \cdot \gamma_2 \qquad \text{(A-15)}$$

$$e_{3n} (S_{3n}, D_{3n}) = ER_{3n} \cdot \gamma_3\ (1/2\ S_{3n} + 1/2\ D_{3n}) \qquad \text{(A-16)}$$

$$e_{4n} = ER_{4n} \cdot \gamma_4 \qquad \text{(A-17)}$$

The production of on-peak firm energy from each of the reservoirs is a function of the storage level and the release. This will be given by:

$$U_{1n} (D_{1n}, S_{1n}) = OPH_n \cdot C_1\ ([\min\ (S_{1n}, D_{1n})], R_1{}^t{}_n)^* \qquad \text{(A-18)}$$

$$U_{2n} = \min\ [OPH_n \cdot C_2, R_{2n}{}^t, h_2] \qquad \text{(A-19)}$$

$$U_{3n} (D_{3n}, S_{3n}) = OPH_n \cdot C_3\ ([\min\ (S_{3n}, D_{3n})], R_{3n}{}^t) \qquad \text{(A-20)}$$

$$U_{4n} = \min\ [OPH_n \cdot C_4, R_{4n}{}^t \cdot h_4] \qquad \text{(A-21)}$$

$$U_{5n} = OPH_n \cdot C_5\ (W_n) \qquad \text{(A-22)}$$

Where

$$R_{1n}{}^t = \min \quad \{R_{1n}, R_1{}^t\max\ (1/2\ S_{1n} + 1/2\ D_{1n})\} \qquad \text{(A-23)}$$

$$R_{2n}{}^t = \min \quad \{R_{2n}, R_2{}^t\max\} \qquad \text{(A-24)}$$

$$R_{3n}{}^t = \min \quad \{R_{3n}, R_3{}^t\max\ (1/2\ S_{3n} + 1/2\ D_{3n})\} \qquad \text{(A-25)}$$

$$R_{4n}{}^t = \min \quad \{R_{4n}, R_4{}^t\max\} \qquad \text{(A-26)}$$

The system is subject to the following constraints:

$$R_{1n}, R_{2n}, R_{3n}, R_{4n}, W_n \geq 0 \qquad \text{(A-27)}$$

$$R_{4n} \geq P_{3n} + \max\ [P_{4n} - DW_{n,0}) - I_{5n} \qquad \text{(A-28)}$$

Since $R_{2n} \geq 0$, we have

$$R_{1n} \geq P_{1n} + e_{2n} - I_{2n} \qquad \text{(A-29)}$$

and $R_{4n} \geq 0$, gives

$$R_{3n} \geq P_{2n} + e_{4n} - I_{4n} \qquad \text{(A-30)}$$

*See page 89 for definition of C_1 and C_3

The storage constraints for the reservoir can be written as:

$$S_1 \text{ min} \leq S_{1n}, D_{1n} \leq S_1 \text{ max } n \qquad \text{(A-31)}$$

$$S_3 \text{ min} \leq S_{3n}, D_{3n} \leq S_3 \text{ max } n \qquad \text{(A-32)}$$

and for the desalination plant,

$$0 \leq W_n \leq n \qquad \text{(A-33)}$$

where W_n is an integer.

Equation (A-8) to (A-32) give a mathematical representation of the system for the incremental dynamic programming model. Equation A-8 gives the recursive relation used for computing the firm on-peak energy, as derived from the state of the system in the period before, and energy productions from each of the reservoirs (equations (A-18) to (A-21) and the desalting plant (equation (A-22)).

The releases from the reservoirs are computed in equations (A-9) to (A-12). (Note that these equations can be used only after a feasible initial policy has been determined). Equation (A-13) gives the quantity of water produced from the desalting plant. The evaporation from each of the reservoirs is calculated in equation (A-16) to (A-17), based on the evaporation rates and storage levels. For reservoirs 2 and 4, the storage level does not affect evaporation as these are constant head reservoirs. The energy productions can now be calculated as in equations (A-18) to (A-22).

To calculate the firm energy production, the minimum release in any period has to be known. This is computed in equations (A-23) to (A-26). The physical constraints on the storage levels and releases are specified in equations (A-27) to (A-33). These are derived from the mass balance equations A-9 to A-12.

The operation of the dynamic programming algorithm is defined in terms of state and decision variables. Thus, the state (M, N) is defined:

$$S_{1n} = S_1^* n + (M-2) \cdot \Delta_1 \qquad \text{(A-34)}$$

$$S_{3n} = S_3^* n + (N-2) \cdot \Delta_2 \qquad \text{(A-35)}$$

There is no state variable for the desalting plant, since there in no storage facility associated with it to carry over production from one period to the next. The Δ_1 and Δ_2 are the increments taken from one period to another in the storage levels, for reservoirs 1 and 3.

The storage constraints for the reservoir can be written as:

$$S1MIN\ (n) \leq S_{1n},\ D_{1n} \leq S1MAX\ (n) \quad \text{(A-31)}$$

$$S3MIN\ (n) \leq S_{3n},\ D_{3n} \leq S3MAX\ (n) \quad \text{(A-32)}$$

and for the desalination plant,

$$0 \leq W_n \leq n \quad \text{(A-33)}$$

where W_n is an integer.

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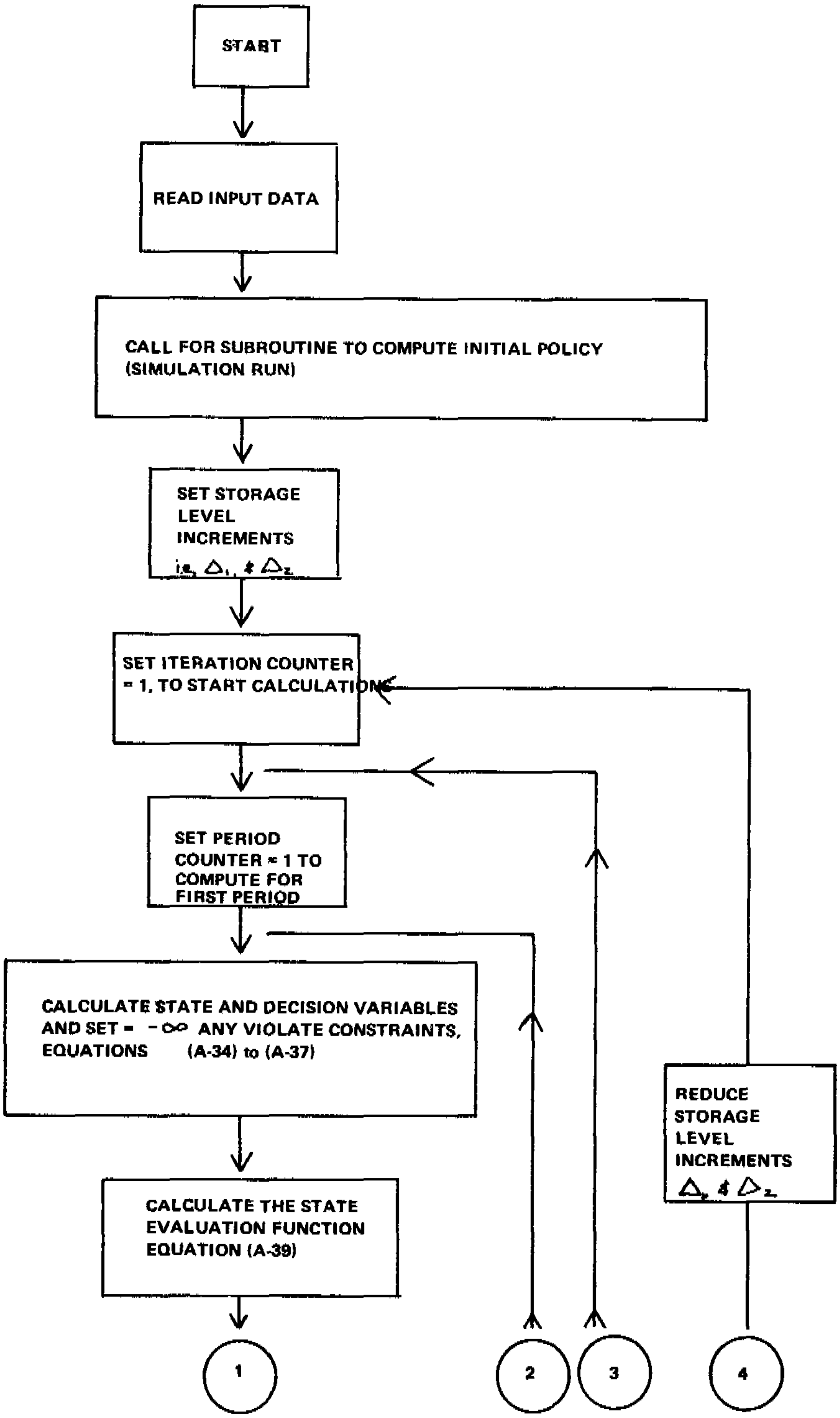
There is no state variable for the desalting plant, since there in no storage facility associated with it to carry over production from one period to the next. The Δ_1 and Δ_2 are the increments taken from one period to another in the storage levels, for reservoirs 1 and 3.

Figure A-3 Flow Chart for Incremental Dynamic Programming



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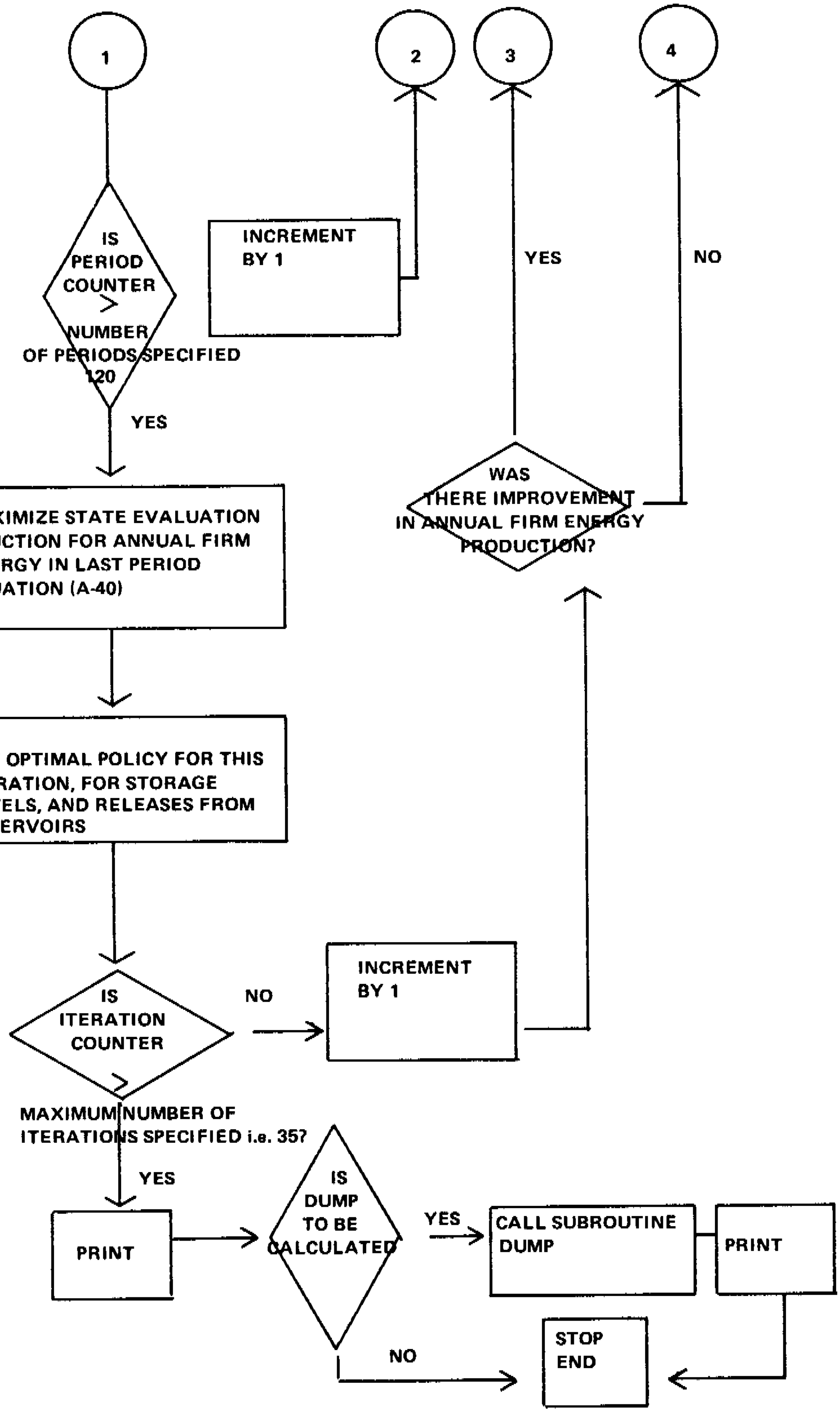


Figure A-3 (Con't.) Flow Chart for Dynamic Programming be computed by replacing the on-peak hours term (OPH_n) in equations (A-18) to (A-22) by the total hour (TH_n) available during the period, for which energy production is possible. This gives the following equations for total energy production

$$U_{1n}(D_{1n}, S_{1n}) = TH_n \cdot C_1([\min(S_{1n}, D_{1n})], R_{1n}{}^t) \quad (A-41)$$

$$U_{2n} = \min[TH_n \cdot C_2, R_{2n}{}^t \cdot h_2] \quad (A-42)$$

$$U_{3n}(D_{3n}, S_{3n}) = TH_n \cdot C_3([\min(S_{3n}, D_{3n})], R_{3n}{}^t) \quad (A-43)$$

$$U_{4n} = \min[TH_n \cdot C_4, R_{4n}{}^t \cdot h_4)] \quad (A-44)$$

$$U_{5n} = TH_n \cdot C_5(W_n) \quad (A-45)$$

Thus, dump energy can be calculated from:

$$DE(n) = \sum_{i=1}^{5} U_{in} - AFE \cdot \alpha_n \quad (A-46)$$

From this, different statistical parameters like the annual dump energy production, mean monthly dump energy production can be computed, as below.

(1) Total Annual Dump Energy

$$ADE(j) = \sum_{n=12j-11}^{12j} DE(n) \quad \text{for every year } j, \text{ where } j=1, \ldots . 10 \quad (A-47)$$

(2) Present value of Annual Dump Energy at rate r

$$PVADE(r) = \sum_{j=1}^{10} ADE(j)/(1+r)j \quad (A-48)$$

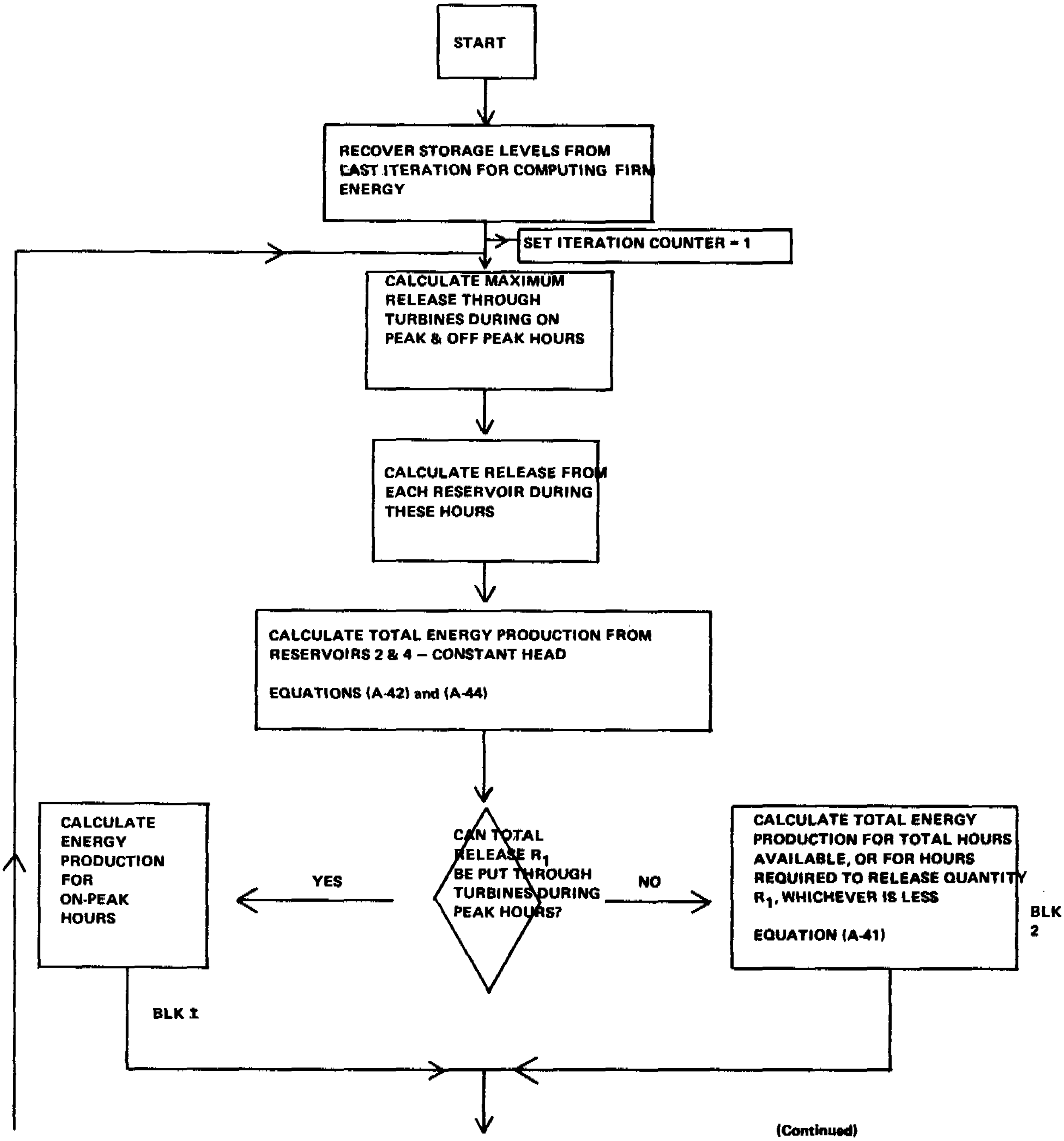
(3) Equivalent Uniform Annual Dump Energy at rate r

$$EVADE(r) = PVADE(r) \quad r \cdot (1+r)^j/[(1+r)^j-1]$$
$$\text{when } j=1, \ldots . 10 \quad (A-49)$$

The dump energy calculations are carried out if required, by a special subroutine, using the incremental dynamic programming model use for firm energy. The logic is explained in the flow chart in Fig. A-4.

A.4 Parallel Reservoir System and Dual Purpose Desalting Plant

A parallel reservoir system is common when there is more than one river flowing through the same basin. Thus, if there are two rivers (or a river and a tributary) flowing near to each other, reservoirs can be constructed on both. A



(Continued)

Figure A-4 Flow Chart for Dump Energy Calculation
SUBROUTINE DUMP

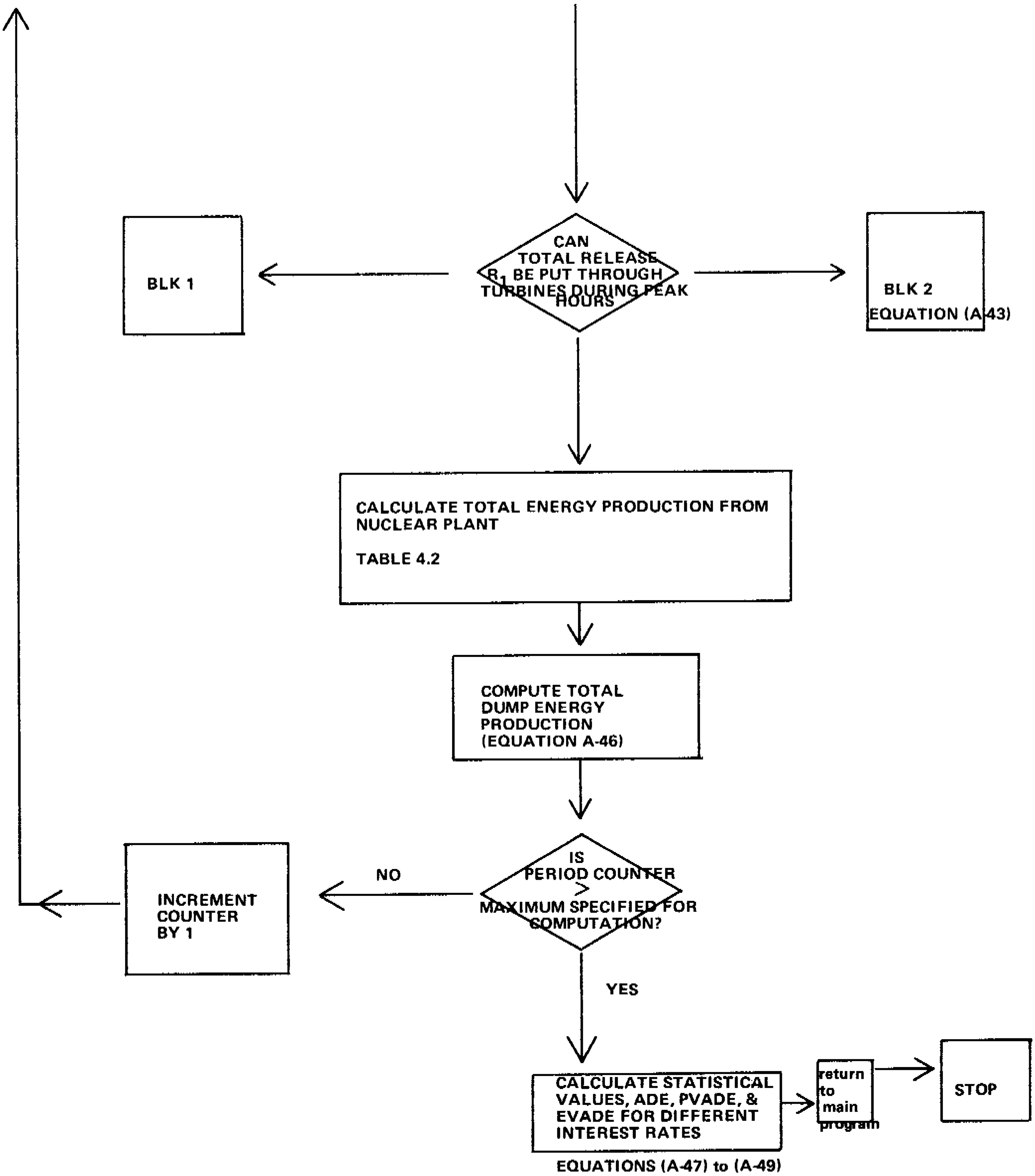


Figure A-4 (Con't.) Flow Chart for Dump Energy Calculation

SUBROUTINE DUMP

mathematical model can be formulated for the analysis of a parallel reservoir system with a dual purpose desalting plant.

The configuration of a parallel reservoir system is shown in Fig. A-5. The reservoirs are the same as those considered for the series system in section (A-1). Reservoirs 1 and 2 are on one branch, and reservoirs 3 and 4 on the second branch of the parallel system. The desalting plant is linked on the downstream side of the reservoirs. As before, all reservoirs are multipurpose, with 1 and 3 being variable head, and 2 and 4 constant head reservoirs.

In the optimal, operation of the conjunctive system,

(1) Upstream demands in both branches of the reservoir system must be met.

(2) The storage constraints on the reservoir and flood control characteristics must be satisfied.

(3) The energy production should be maximized for a given firm water level.

The overall firm water output of the system P_4 governs the energy production from the system. As before, the simulation model is used for the determination of maximum firm water output, and incremental dynamic programming for energy production.

The operation of a parallel reservoir is somewhat different from a series system. The releases from reservoirs 1 and 2 satisfy all the requirements in one branch and the releases from reservoirs 3 and 4 satisfy the requirements in the second branch. The overall water demand on the system, P_4, is met by the water from the desalting plant, and the releases R_2 and R_4 from the two branches. The level of releases R_2 and R_4 is a variable, in that R_2 can be decreased and R_4 increased by the same amount, to satisfy the net demand. Changing R_2 and R4 will change the hydroelectric production. Thus, R_2 and R4 should be chosen so as to maximize the electricity production.

Since reservoirs 2 and 4 are constant head reservoirs, the releases R_2 and R_4 will depend on the releases R_1 and R_3 respectively, the inflows, and water requirements due to evaporation, local demands, etc. Thus, to meet the water requirements P_3 and P_4, which are external to the two branches of the parallel reservoir system, releases R_1 and R_3 should be sufficient. It is assumed that a portion of the demand P_3 is satisfied from reservoir 1, and the rest from reservoir 3. Similarly, a portion of the demand P_4 is satisfied from reservoir 1, and the rest from reservoir 3. If θ and ρ are

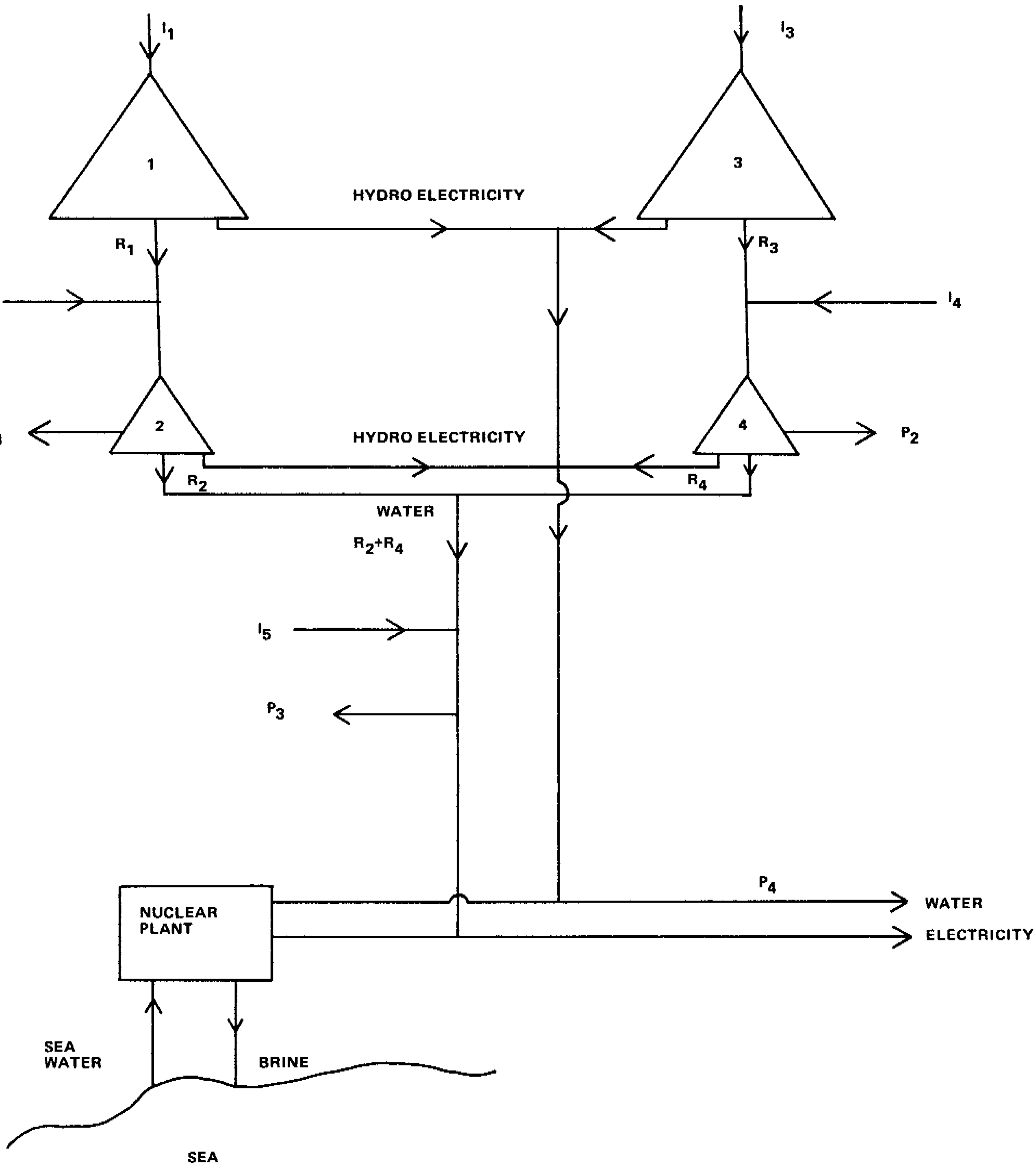


Figure A-5 Parallel Reservoir Configuration the fractions of demands P_3 and P_4 which have to be satisfied by reservoir 1, then we have:

External demands to be satisfied by reservoir 1:

$$\theta P_3 + \rho P_4 \tag{A-42}$$

And External demands to be satisfied by reservoir 3:

$$(1 - \theta)P_3 + (1 - \rho)P_4 \tag{A-43}$$

With $0 \leq \theta \leq 1$
$0 \leq \rho \leq 1$

The total external demand will then be the summation of the two equations, thus

$$\text{Total external demand} = P_3 + P_4 \tag{A-44}$$

If desalting is also in operation, the external demands will be reduced by the quantity of water produced from desalting.

To find the optimal combination of θ and ρ, a unidimensional search should ideally be carried out over all possible values. This would involve excessive computations, and some simplifying assumptions are made to determine the optimum θ and ρ. It is assumed that θ and ρ can take the values from .3 to .7, in intervals of .1. Thus, there are five values of θ and ρ, and 25 possible combinations. The optimal value of θ and ρ can then be determined corresponding to the combination which gives maximum hydroelectricity production.

The logic of the simulation and incremental dynamic programming models is the same as for series reservoirs. An initial policy is first determined from simulation, and using this as an input to the dynamic programming model, the firm and dump energy productions can be computed. The backward recursive equations for minimum storage levels (A-1 and A-2), are replaced by:

$$\begin{aligned} \text{S1MIN}(n) = \max \; & \{\text{S1DEAD}, \min\,[\text{S1MIN}(n+1), \text{S1MAX}] - I_{1n} + e_1(S, D) \\ & - \min\,[I_{2n} - P_{1n} - e_{2n} - \theta \cdot (P_{3n} - I_{5n}), 0]\} \end{aligned} \tag{A-45}$$

$$\begin{aligned} \text{S3MIN}(n) = \max \; & \{\text{S3DEAD}, \min\,[\text{S3MIN}(n+1), \text{S3MAX}] - I_{3n} + e_3(S, D) \\ & - \min\,[I_{4n} - P_{2n} - e_{2n} - (1-\theta)(P_{3n} - I_{5n}), 0]\} \end{aligned} \tag{A-46}$$

The recursive relation for the dynamic programming model is given by:

$$f_n\,(S_{1n}, S_{3n}) = \max_{D_{1n}, D_{3n}, W_n} \{\min\,[\sum_{i=1}^{5} U_{in}/\alpha_n,\; f_{n-1}\,(S_{1,\,n-1}, S_{3,\,n-1})]\} \tag{A-47}$$

Where $S_{1\ n-1} = D_{1n}$; $S_{3\ n-1} = D_{3n}$

The releases from the different reservoirs are given by:

$$R_{1n} = D_{1n} + I_{1n} - S_{1n} - e_{1n}\ (S_{1n},\ D_{1n}) \qquad \text{(A-48)}$$
$$R_{2n} = R_{1n} + I_{2n} - P_{1n} - e_{2n} \qquad \text{(A-49)}$$
$$R_{3n} = D_{3n} + I_{3n} - S_{3n} - e_{3n}\ (S_{3n},\ D_{3n}) \qquad \text{(A-50)}$$
$$R_{4n} = R_{3n} + I_{4n} - P_{2n} - e_{4n} \qquad \text{(A-51)}$$

Desalinized water production will be the same as before, that is:

$$DW_n = b_n \cdot W_n \qquad \text{(A-52)}$$

The constraints on the system are:

$$R_{1n},\ R_{2n},\ R_{3n},\ R_{4n},\ W_n \geq 0 \qquad \text{(A-53)}$$

Thus, from $R_{2n} \geq 0$, we get from equation (A-49)

$$R_{1n} \geq P_{1n} + e_{2n} - I_{2n} \qquad \text{(A-54)}$$

and from $R_{4n} \geq 0$ and equation (A-51) we get

$$R_{3n} \geq P_{2n} + e_{4n} - I_{4n} \qquad \text{(A-55)}$$

The joint water supply to meet the requirements external to the two parallel branches will then be given by

$$R_{2n} + R_{4n} \geq P_{3n} + \max\ (P_{4n} - DW_n,\ 0) - I_{5n} \qquad \text{(A-56)}$$

The storage constraints, desalting plant constraints, equations (A-31) to (A-33), remain the same as before. The equations for evaporation (A-14) to (A-17), energy production (A-18) to (A-22), and releases (A-23) to (A-26) are also unchanged.

The computer algorithms work in the same way as for the series reservoirs, and only a few equations have to be altered. The logic of the computer models remains the same, and can be followed from the flowcharts A-2 to A-4.

APPENDIX B
USER'S MANUAL

This appendix describes the use of the conjunctive use computer programs on an IBM 360/65 system. All the parameters and the input formats are defined here. Once raw data is available from any system configuration, the details in this section enable one to set up the data decks.

B.1 Series Reservoir System

This section gives a detailed explanation of all the terms used and the input parameters required. Most of these parameters are also used for the parallel reservoir system, which is discussed in B.2.

Input Data Requirements

DEFINITIONS

The following definitions serve to identify the input requirements of the program. Every variable name is presented and defined in the order it is read into the computer. The field position and width of each variable on a card are defined by giving the beginning and ending (inclusive) card column numbers. For those variables that are arrays, the limit on each of the array indices is explicitly stated and the format specification used for reading the input is also given. Whenever applicable, the options available for a variable are presented. Unless otherwise stated assume every variable must be specified and may not equal zero. All integer variables must be right-hand justified in their respective fields.

FORTRAN DATA STATEMENT

Since the program is designed to be adaptable to various reservoir configurations, some data must be supplied internally to the program in the form of a FORTRAN Data Statement. This statement is the first card of the program after the job control cards. The following definitions refer to the variables specified in this Data Statement.

<u>IPTR</u> The FORTRAN data set number for the printer.

<u>IRDR</u> The FORTRAN data set number for the card reader.

<u>N YEARS</u> The number of years in the study. This number must be less than or equal to 10 years.

<u>LSTOR1</u> Due to the digital nature of the computer, it is necessary to break the storage capacity of the

reservoirs into discrete levels of storage. Of course, all variables that are functions of the storage level are similarly discretized. LSTOR1 is the number of discrete storage levels for variable-head reservoir 1 (see the definition of DS1 to determine how this variable is fixed). Must be less than or equal to 80.

LSTOR3 The number of discrete storage levels for variable-head reservoir 3 must be less than or equal to 80.

NREL1 The number of discrete release levels (see the definition of DR1 to determine how this variable is fixed) for variable-head reservoir 1. Must be less than or equal to 80.

NREL3 The number of discrete release levels for variable-head reservoir 3 must be less than or equal to 80.

As an example,

The format for this Data Statement for the case investigated is as follows:

```
DATA IPTR/6/, IRDR/5/, N YEARS/10/,
LSTOR1/20/, LSTOR3/27/, NREL1/16/, NREL3/26/
```

These variables must be specified in this way so that the FORTRAN compiler will be able to read the correct amount of information into the discretized variables that are functions of storage, release, and/or the number of years in the study. This statement is followed by the main program and subroutines, after which we have the data deck. All the input parameters are defined below, as they are read in from the data deck.

Card A: Program Control Card This card fixes the parameters that control the operation and options of the program.

MUNITS Columns (1-2), integer. This variable is the maximum number of desalination units available. This variable must be less than or equal to 7 and strictly greater than zero. If no desalination is to be used, set MUNITS equal to 1.

CAPDES Columns (7-14), real variable. The capacity of the desalting plant in millions of gallons per day. When no desalination is to be used this variable must be set equal to zero.

INTPOL Columns (15-17), integer. This is the initial policy option flag.

5 = use maximum desalination capacity in the determination of the initial policy

1 = use zero desalinized water capacity to determine the initial policy

ISIM Columns (18-20), integer. The Simulation-Dynamic Programming option flag.

1 = perform simulation only. Program does not determine annual firm energy levels.

0 = determine annual firm energy as well as simulation (initial policy).

This flag is used primarily to investigate the affect of desalination on the initial policy (see the definition of MAXP4).

ITRTOT Columns (21-23), integer. This is the total number of iterations of the program. This variable must be less than or equal to 35.

OPMAX Columns (24-31), real variable. This variable is an operating maximum storage level for reservoir 3. It is used in the determination of the initial policy as an indication of when it might be necessary to start releasing from reservoir 3. This variable should be about 10 to 15 percent below the smaller maximum storage level for reservoir 3 (see the definition of S3MAXA).

MAXP4 Columns (32-34), integer. MAXP4 is the option flag to determine the maximum water demand P_{4R}, which the system can satisfy.

1 = find the maximum P_4 the system can satisfy and use this maximum P_4 to determine the initial policy.

0 = use the given P_4 (see ANPUMP) to determine the initial policy.

Using MAXP4 and ISIM it is possible to determine the maximum demand which can be satisfied at P_4 due to conjunctive operation without calculating the annual firm energy. That is, with ISIM on (=1), and MAXP4 on, the program could be run twice (for a given value of DESCAP) once with INTPOL on (=5) and once with INTPOL off (=10) and the difference in the maximum P_4 is due to desalination alone.

ID Card Columns (35-37), integer. This is the dump energy analysis flag.

1 = Perform dump energy analysis

0 = Do not perform dump energy analysis

Card B: Annual Demand Card

ANPUMP(I), I = 1 to 4

There are four pumping demands in the system: P_1, P_2, P_3, and P_4. ANPUMP(I) is the total annual demand at station I, in thousands of acre-feet. That is, if the total annual demand at P_2 is 250,000 acre-feet, the number entered in ANPUMP(2) is 250.0. Any of these pumping demands may be set equal to zero in order to adapt the program to a specific system. If this is done, the corresponding demand distribution is arbitrary but still required. That is, if the second demand is zero, set P(2,J) = 0.0 for J = 1 to 12. Furthermore, if the MAXP4 option flag is on (=1), the search for the largest P_4 the system can supply converges much faster from below. That is, the program is much more efficient if ANPUMP(4) is set lower than the expected maximum. FORMAT (4F6.3)

Card C: Low Pressure Turbogenerator Energy Capacity Card

C6(I), I = 1 to 8

This array is the energy capacity of the turbogenerator using low pressure steam in megawatts when (I-1) desalting units are in operation. For example, if zero desalting units are in operation for 5 hours, (C6(1)*5 megawatt-hours are produced. Note that if desalination is not being considered (DESCAP = 0.0), then C6(I) must = 0.0 for all I. FORMAT (8F6.3) The energy capacities are taken from Tables in Appendix D.

Card D: Pumping Demand Distribution

P(I, J), J = 1 to 12, I = 1 to 4

This two dimensional array is the pumping demand distribution for the four demands. That is, P(I, J) is the percentage of the annual demand needed in month J at pumping station I. FORMAT (12F6.3)

Card E: Surface Areas for Reservoir 1 & Reservoir 3

AREA 1 (I), I = 1 to LSTOR1

This array is the surface area of the variable-head reservoir 1 at discrete storage level I (in thousands of acres). For example, if the fifth storage level was 30,000 acre-feet and the surface area at that level was 11,436 acres, then AREA (5) = 11.436. FORMAT (10F8.3)

AREA 3 (I), I = 1 to LSTOR3

This array is the surface area of variable-head reservoir 3 at discrete storage level I (in thousands of acres). FORMAT (10F8.3)

Card F: Constant Head Areas

AREA (I), I = 1 to 4

This array contains the surface area of the constant head reservoirs in thousands of acres. AREA (1) and AREA (3) = 0.0 (corresponding to the variable-head reservoirs). If a constant head reservoir is to be eliminated from the system, the corresponding element of AREA would be set equal to zero. FORMAT (4F6.3)

Card G: Discrete Increments Card

DS1

Columns (1-7) real variable. This variable is the discrete storage level increment for reservoir 1 in thousands of acre-feet. That is, DS1 is the difference between the discrete storage levels used in all variables that are a function of storage (e.g., AREA 1). The choice of this variable fixes the size of LSTOR1. For example, in the present study the maximum storage for reservoir 1 was 992,475 acre-feet. The choice of DS1 = 50.0 (i.e., 50,000 a.f.) then gives 992.475/50.0 = 19.85. This means that LSTOR1 must equal 20. Furthermore, LSTOR1 would have to be 20 even if the ratio of (maximum storage)/DS1 = 19.15. Although no variable that is a function of storage can exceed the value corresponding to maximum storage, intermediate values are reached via linear interpolation. Hence, all variables that are a function of storage must be linearly extrapolated to a storage level (exceeding maximum storage) that is an integral multiple of DS1 (here 20*50. = 1000.0). For example, AREA 1 (20) would be the surface area of reservoir 1 if it could reach a storage level of 1,000,000 acre-feet. In order to avoid errors due to linear interpolation of non-linear phenomena the minimum ratio of (maximum storage)/DS1 should be approximately 15.

DR1

Columns (8-14), real variable. This variable is the discrete release increment for reservoir 1 in cubic feet per second. It is determined in the same way as DS1 except the critical ratio is (maximum release through the turbine in cubic feet per second)/DR1. Now the maximum possible turbine release will vary with the storage level. Furthermore, the overall maximum turbine release considered over all possible storage levels need not occur at the maximum storage. Therefore, care must be taken to assure that the maximum turbine release over all storage levels is used in the above ratio to determine DR1 (and hence

NREL1). Again, the minimum value for DR1 should be such that the value of NREL1 is approximately 16.

DS3 Columns (15-21), real variable. This variable is the discrete storage increment for reservoir 3 in thousands of acre-feet. It is chosen in the same way as DS1. One procedure that might be used to fix DS1 and DS3 is to use the smaller variable-head reservoir to fix one increment size so that the ratio is near 15. Then use this same increment size for the other storage increment if this does not result in the number of storage levels of the larger variable-head reservoir being too large.

DR3 Columns (22-28), real variable. This variable is the discrete release increment for reservoir 3 in cubic feet per second. Since the maximum release through the turbines in cfs is a function of the physical plant characteristics, NREL3 might be much larger than NREL1 (or vice versa) for the same release increment size. This isn't a problem unless the number of both storage and release levels approaches 35 for the same reservoir. Then, any variable that is a function of both storage and release would have to have 35^2 values specified and data preparation becomes a problem.

S1DEAD Columns (29-35), real variable. This is the dead storage of reservoir 1 in thousands of acre-feet.

S3DEAD Columns (36-42), real variable. This is the dead storage of reservoir 3 in thousands of acre-feet.

Card H: Variable Head Energy Capacities

C1 (I, J), J = 1 to NREL1, I 1 to LSTOR1
This array contains the energy capacity of reservoir 1 in megawatts as a function of storage and release. That is, at a given storage level S, and release r, the megawatt-hours produced in 5 hours is C1 (S, r)*5. FORMAT (10F7.3)

C3 (I, J), J = 1 to NREL3, I = 1 to LSTOR3
This array contains the energy capacity of reservoir 3 in megawatts as a function of storage and release. As implied by the order of the indices limits above, J varies fastest in the data deck. That is, the

data must be prepared so that at a given storage level, the energy capacities for all release levels are read into the capacity array. For example, C1 data is read into the program by an implied DO loop of the following form:

((C1 (I, J), J = 1, NREL1), I = 1, LSTOR1).

FORMAT (10F7.3)

Card I: Constant Head Energy Capacities

C (I), I = 1 to 4

Here C (I) contains the constant head energy capacities in megawatts. As with AREA (I), only C (2) and C (4) contain non-zero values. If one (or both) of the constant head reservoirs is not to be considered, the corresponding C (I) must have the value zero. FORMAT (4F6.3)

Card J: Storage Extrema Card

S1MAX — Columns (1-10), real variable. This variable is the maximum storage of reservoir 1.

S3MAX A — Columns (11-20), real variable.

S3MAX B — Columns (21-30), real variable. These two variables represent the maximum storage in thousands of acre-feet of reservoir 3. That is, S3MAX A is a storage level slightly below S3MAX B, The actual water volume limit of reservoir 3. In order to provide flood control, it is permissible to exceed the S3MAX A storage level for only one period (month). In the following period, it is required to release so that the storage level at the end of the period is below S3MAX A. If this capability is not desired, set S3MAX A = S3MAX B = Water Volume Limit (in thousands of acre-feet) of reservoir 3.

SINIT 1 — Columns (31-40), real variable.

SINIT 3 — Columns (41-50), real variable. These variables are the initial storage levels in thousands of acre-feet of reservoir 1 and reservoir 3 respectively. Both values should be about 5 percent below maximum storage since the program is based on critical period hydrology.

C5 — Columns (51-60), real variable. This variable is the energy capacity of the low pressure steam turbogenerator plants in megawatts. If these plants are not to be considered, C5 must equal zero.

Card K: Maximum Turbine Release

(The maximum turbine release is based on the capacity of the penstock and of course the net head, i.e., reservoir storage level and tail water elevation.)

R1MAXT(I), I = 1 to LSTOR1
This array contains the maximum possible release in cubic feet per second through the turbines of reservoir 1 at storage level I. FORMAT (10F8.3)

R3MAXT(I), I = 1 to LSTOR3
Same as R1MAXT but for reservoir 3. FORMAT (10F8.3)

Card L: Evaporation Rates

ERATE (I, J), J = 1 to 12, I = 1 to 4
This array contains the evaporation rate for reservoir I in month J in feet. The twelve monthly rates are read into array first. That is, an implied DO loop of the form
((ERATE (I, J), J = 1, 12), I = 1, 4)
is used to read the data. FORMAT (12F6.3)

Card M: Constant Head Turbine Release

RMTCFS(I), I = 1 to 4
For I = 2, 4 this variable is the maximum possible release through the turbine in cubic feet per second. For I = 1, 3 this variable = 0.0. If one (or both) of the variable-head reservoirs is to be deleted, set the corresponding RMTCFS(I) equal to zero. FORMAT (4F6.3)

Card N: On Peak Hours

OPH(I), I = 1 to 12
This array contains the number of on-peak hours in month I. FORMAT (12F5.0)

Card O: Annual Firm Energy Distribution

ALPHA(I), I = 1, 12
This array contains the decimal percentage of the total annual on-peak energy demand needed in month I. FORMAT (12F5.0)

Card P: Constant Head Energy Rates

ENRATE(I), I = 1 to 4
For I = 2, 4 ENRATE(I) is the energy rate of the constant head reservoirs. That is, the

megawatt-hours produced for each 1,000 acre-feet released. For I = 1, 3 ENRATE(I) = 0.0. Again, if the constant head reservoirs are to be ignored, set the corresponding ENRATE(I) equal to zero. FORMAT (4F6.3)

Card P: Constant Head Energy Rates

ENRATE(I), I = 1 to 4

For I = 2, 4 ENRATE(I) is the energy rate of the constant head reservoirs. That is, the megawatt-hours produced for each 1,000 acre-feet released. For I = 1, 3 ENRATE(I) = 0.0. Again, if the constant head reservoirs are to be ignored, set the corresponding ENRATE(I) equal to zero. FORMAT (4F6.3)

Card Q: State Increment Increments

DEL1(I), I = 1 to 10, real variables
DEL2(I), I = 1 to 10, real variables

These arrays contain the stated increments in thousands of acre-feet developed in connection with the stated increments dynamic programming. Experience has shown that one way to pick these values is to take the largest increment to be 10 percent of the maximum storage of the smaller variable head reservoir after "rounding up." For example, in this study, S1MAX was 992.475 and the largest increment was taken to be 100. the remaining eight increments were then 50., 25., 10., 5., 1.0 1.0, 1.0 1.0. There were only eight choices left because DEL1(1) = DEL2(1) = 0.0 in order to evaluate the annual firm energy of the initial policy. If the initial choice of the largest increment produces a large increase over the initial policy and the total increase seems a little low, try a larger value for the first increment. For example, another set of increments that might have been tried for this study under these conditions might have been: 0.0, 125., 100., 75., 50., 25., 15., 10., 5.0, 1.0. FORMAT (10F7.3)

LIMDEL(I), I = 1 to 10, integer

One reason the choice of DEL1(I) and DEL2(I) is not very sensitive is this array. LIMDEL(I) is the maximum number of times of the DEL1(I), DEL2(I) pair is to be used before going to the next pair. Actually the way the program is set up, we use the same DEL1(I), DEL2(I) pair as long as it produces a 5% increase over the Annual firm energy (AFE) of the previous iteration. We use this pair only LIMDEL (I) times if the AFE increases less than 5%. The first time the AFE of the current iteration does not improve at all, we use the next pair of DEL1(I), DEL2(I) if there are any pairs left. If there are no pairs left we divide the current pair in half and continue iterating. FORMAT (10I3)

Card R: Water Inflows

FLOWIN (I, J), J = 1 to N MONTH, I = 1 to 5

There are five inflows to the system: I_1, I_2, I_3, I_4, and I_5.

FLOWIN (I, J) is the inflow at station I during month J where N MONTH = N YEARS *12. The inflow at each station is read into FLOWIN (I, J) first. That is, an implied DO loop of the following form reads this data:

((FLOWIN (I, J), J = 1, N MONTH), I = 1, 5)
Any of these inflows may be set equal to zero to adapt to a specific system. FORMAT (10F8.3). In the present study, FLOWIN (I, J), I = 5 is set equal to zero, that is the inflow I5 = 0 in all periods.

For the case considered, a sample input data deck is given below. The letters in parentheses correspond to the card descriptions in the text.

PRINTOUT FORMATS

The first thing printed out by the program under the general heading of system characteristics is the input data and a few derived parameters. The printout formats of these parameters are self-explanatory with the following elaborations:

(1) When the energy capacities of the two variable-head reservoirs are printed out, release levels increase horizontally and a blank line separates each storage level.

(2) RIMAX T is the maximum turbine release during the on peak hours of each month in thousands of acre-feet for the two constant head reservoirs. Here, and throughout the system characteristics printout, the months increase horizontally and the station vertically.

(3) DESCAP is the monthly desalination capacity in thousands of acre-feet.

4	300.0	1	0	3	1100.0	1	1	(A)	

11.	39	517.32	900.0	(B)	

0.	0.	0.	0.	0.	0.	0.	0.	(C)

.061	.055	.065	.070	.075	.107	.140	.130	.094	.077	.065	.061	
.061	.055	.065	.070	.075	.107	.140	.130	.094	.077	.065	.061	
.000	.000	.016	.087	.153	.200	.189	.178	.146	.030	.001	.000	(D)
.061	.055	.065	.070	.075	.107	.140	.130	.094	.077	.065	.061	

2.86	4.98	6.85	8.53	9.89	11.31	12.6	13.76	14.79	
15.82	16.73	17.63	18.4	19.05	19.82	20.47	21.11	21.75	(E)
22.47	23.37								

1.82	3.12	4.25	5.38	6.3	7.1	7.88	8.65	9.32	
10.1	10.62	11.3	12.02	12.7	13.3	13.98	14.58	15.25	
15.98	16.6	17.25	18.	18.65	19.25	20.	20.6	21.25	(E)
21.95	22.55	23.15							

0.0	6.375	0.0	1.1830	(F)

50.	100.	50.	100.	36.8	27.9	(G)

CS (I, J)

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
0.	1.2	2.05	2.85	3.65	4.4	5.	5.6	6.15	6.7	
7.	7.15	0.	0.	0.	0.	0.	1.35	2.25	3.15	
3.95	4.7	5.4	6.1	6.75	7.35	7.75	8.017	0.	0.	
0.	0.	0.	1.5	2.45	3.3	4.15	5.	5.75	6.5	
7.25	7.9	8.35	8.65	9.15	0.	0.	0.	0.	1.65	
2.55	3.5	4.4	5.3	6.15	6.9	7.7	8.4	8.9	9.25	
9.472	0.	0.	0.	0.	1.75	2.75	3.7	4.65	5.5	
6.35	7.15	7.95	8.7	9.35	9.8	10.16	0.	0.	0.	
0.	1.9	2.85	3.8	4.75	5.7	6.6	7.5	8.35	9.1	
9.8	10.35	10.75	11.08	0.	0.	1.	2.	3.	4.	
4.95	5.9	6.8	7.75	8.6	9.4	10.15	10.8	11.3	11.8	
0.	0.	1.15	2.1	3.05	4.05	5.05	6.05	7.	8.	(H)
8.9	9.75	10.55	11.2	11.7	12.1	0.	0.	1.2	2.15	
3.15	4.2	5.2	6.2	7.2	8.15	9.15	10.1	10.85	11.5	
11.95	12.31	0.	0.	1.25	2.25	3.3	4.3	5.35	6.35	
7.35	8.4	9.4	10.45	11.15	11.75	12.15	12.48	0.	0.	
1.35	2.4	3.45	4.5	5.55	6.6	7.65	8.75	9.75	10.8	
11.85	12.25	12.61	0.	0.	0.	1.4	2.5	3.6	4.7	
5.8	6.9	8.	9.1	10.25	11.25	12.15	12.85	0.	0.	
0.	0.	1.5	2.65	3.8	4.9	6.	7.15	8.25	9.4	
10.5	11.6	12.	0.	0.	0.	0.	0.	1.5	2.7	
3.9	5.	6.15	7.3	8.4	9.6	10.7	11.8	12.88	0.	

1.65	2.85	4.	5.2	6.35	7.5	8.65	9.8	10.95	12.1
13.43	0.	0.	0.	0.	0.	1.75	2.9	4.05	5.25
6.4	7.55	8.75	9.85	11.05	12.2	13.7	0.	0.	0.

C3 (I, J)

.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	4.1	4.75	5.4	5.95
6.4	6.85	7.3	7.75	8.375	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.2	4.95	5.7	6.45	7.15	7.85	8.55	9.2	9.9	10.55
11.25	11.9	12.4	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	4.15	5.05	5.85	6.7	7.55
8.4	9.2	10.	10.9	11.7	12.5	13.3	13.95	14.45	14.84
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	4.6	5.55	6.5	7.45	8.4	9.3	10.25	11.2	12.15
13.05	13.9	14.7	15.45	16.15	16.6	16.93	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	4.95	6.	7.
8.	9.	10.1	11.1	12.1	13.1	14.1	15.1	16.05	16.9
17.65	18.25	18.75	19.04	0.	0.	0.	0.	0.	0.
0.	0.	4.2	5.3	9.4	7.5	8.6	9.75	10.85	11.95
12.95	14.	15.1	16.15	17.15	18.05	18.9	19.6	20.25	20.75
22.61	0.	0.	0.	0.	0.	0.	0.	4.5	5.65
6.75	7.9	9.05	10.25	11.35	12.5	13.6	14.7	15.9	17.
18.	19.05	20.	21.	21.65	22.15	22.7	23.45	0.	0.
0.	0.	0.	0.	4.65	5.8	7.	8.2	9.4	10.6
11.8	13.	14.15	15.35	16.55	17.75	18.9	19.95	20.85	21.75
22.55	23.25	23.8	24.3	0.	0.	0.	0.	0.	0.
4.9	6.	7.1	8.2	9.5	10.7	12.	13.2	14.45	15.7
6.95	18.15	19.45	20.5	21.45	22.4	23.2	23.75	24.25	24.58
0.	0.	0.	0.	0.	4.	5.05	6.25	7.4	8.65
9.9	11.15	12.45	13.65	14.95	16.2	17.5	18.7	19.9	21.1
22.2	23.2	24.	24.55	25.22	0.	0.	0.	0.	0.
0.	4.85	5.95	7.2	8.45	9.65	10.9	12.1	13.35	14.55
15.85	17.2	18.45	19.75	20.95	22.1	23.25	24.25	25.25	0. (H)
0.	0.	0.	0.	0.	0.	0.	5.	6.25	7.45
8.65	9.95	11.25	12.4	13.65	14.9	16.3	17.55	18.9	20.2
21.45	22.75	23.8	25.06	0.	0.	0.	0.	0.	0.
0.	0.	0.	5.15	6.45	7.7	9.	10.3	11.55	12.75
13.95	15.25	16.7	18.05	19.4	20.7	21.95	23.25	24.4	25.6
0.	0.	0.	0.	0.	0.	0.	0.	4.	5.25
6.55	7.85	9.1	10.5	11.75	13.	14.35	15.65	17.1	18.5
19.85	21.2	22.55	23.9	25.14	0.	0.	0.	0.	0.
0.	0.	0.	0.	4.05	5.3	6.65	7.95	9.25	10.65
11.9	13.2	14.65	15.95	17.4	18.85	20.2	21.6	23.	24.3
25.7	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.1	5.4	6.75	8.1	9.4	10.75	12.05	13.35	14.85	16.15
17.6	19.05	20.45	21.9	23.35	24.75	26.	0.	0.	0.
0.	0.	0.	0.	0.	0.	4.15	5.45	6.85	8.2
9.5	10.85	12.2	13.5	14.9	16.3	17.75	19.2	20.7	22.15
23.6	25.07	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	4.35	5.7	7.15	8.55	9.7	10.35	12.7	14.1
15.5	16.65	18.45	19.8	21.25	22.55	24.1	25.48	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	4.4	5.8
7.35	8.85	9.95	10.65	13.05	14.5	15.9	17.05	19.	20.3
1.65	23.	24.6	25.49	0.	0.	0.	0.	0.	0.

```
 0.0     0.0     0.0     0.0     4.45    5.9     7.3     8.7    10.10 11.70
13.15   14.6    16.     17.3    19.05   20.40   21.8    23.2    24.75 25.75
 0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0   0.0
 4.75    5.95    7.45    8.90   10.35   11.8    13.25   14.75   16.2  17.65
19.15   20.6    22.05   23.5     0.0     0.0     0.0     0.0     0.0   0.0
 0.0     0.0     0.0     0.0     0.0     0.0     4.55    6.05    7.55  8.95
10.5    11.9    13.45   15.     16.45   16.95   19.5    20.95   22.3  23.85
 0.0     0.0     4.6     6.1     7.65    9.00   10.65   12.     13.65 15.15
16.65   17.15   19.75   21.25   22.55   23.15   26.      0.0     0.0   0.0
 0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     4.65  6.15
 7.75    9.25   10.75   12.3    13.8    15.3    16.85   18.35   19.9  21.35
22.8    24.35   25.79    0.0     0.0     0.0     0.0     0.0     0.0   0.0
 0.0     0.0     0.0     0.0     4.75    6.25    7.8     9.3    10.85 12.4
 3.9    15.4    16.95   18.5    20.5    21.55   23.     24.45   26.28  0.0
 0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0   0.0
 4.8     6.3     7.85    9.35   10.9    12.45   13.95   15.5    17.05 18.6
20.10   21.65   23.15   24.7    26.7     0.0     0.0     0.0     0.0   0.0
 0.0     0.0

0.      50.     0.      15      (I)

992.475     1165.0     1350.0     900.00     1165.00     0.0     (J)

0.      0.      0.      1335.     1375.     1410.     1445     1470     1515  (K)
1540.   1550    1555.   1530.     1455.     1350.     1290.    1265.    1245
1230.   1220.

1750.   1840.   2060.   2190.   2290.   2385.   2470.   2520.   2530.
2530.   2430.   2275.   2195.   2150.   2085.   2050.   2020.   1995.
1965.   1945.   1925.   1900.   1890.   1865.   1845.   1830.   1815.
0.      0.      0.

0.03  0.02  0.16  0.07  0.13  0.47  0.74  0.73  0.36  0.40  0.27  0.10
0.03  0.02  0.16  0.07  0.13  0.47  0.74  0.73  0.36  0.40  0.27  0.10
0.03  0.02  0.16  0.07  0.13  0.47  0.74  0.73  0.36  0.40  0.27  0.10
0.03  0.02  0.16  0.07  0.13  0.47  0.74  0.73  0.36  0.40  0.27  0.10

0.      9000.     0.      3045.     (M)

468.  414.  469.  494.  463.  475.  475.  455.  425.  493.  444.  468.  (N)

.066.  .074  .078  .067  .066  .105  .133  .109  .081  .092  .071  .058 (O)

0.      71.     0.      53.      (P)

0.     100.0    50.0    25.0    10.0    5.0    1.    1.    1.    1.
0.     100.0    50.0    25.0    10.0    5.0    1.    1.    1.    1.   (Q)
1      5     5     5     5    5     5     5     5     5

                         Flowin (I, J):   (R)
  49.197  52.765   48.132   26.108  233.128   57.797  66.367   30.88    90.501
  21.686  31.457   36.396   50.853   70.158  135.653  52.51    59.189  450.253
  13.808  63.392   15.245   16.371   23.044   34.537  17.751   12.108  115.301
  10.88    8.136  153.854   62.974   29.220   44.672  29.035   22.457   30.361
 306.115  42.035   16.256    5.521   12.35    44.498  14.188   46.164   10.914
  31.295  19.672   76.898   59.015  327.041   41.734  39.758   19.994    9.307
  57.337  24.898  102.492  414.969  368.780  105.316  22.123   22.814   28.516
  21.444  11.5     14.969   29.75     8.228   42.925  96.054   31.964   31.226
  84.383  11.442    5.727    6.278    6.633    7.482   6.908    9.812  139.665
```

19.154	37.008	9.675	4.236	4.844	5.039	5.463	4.832	3.881
176.644	36.777	3.067	2.356	283.694	9.686	29.669	25.324	15.946
74.696	21.387	101.356	5.211	26.926	127.874	19.304	176.406	15.463
21.26	20.92	19.45	10.44	53.01	20.07	3.95	6.06	13.7
7.4	11.71	28.08	28.11	21.18	29.52	8.7	5.14	2.71
2.58	8.31	4.1	5.01	8.58	10.58	5.92	32.66	45.05
1.57	.469	12.05	12.3	6.26	5.49	41.73	10.26	18.83
14.56	14.36	3.64	2.17	1.68	1.82	3.38	4.67	4.53
4.87	6.31	13.28	182.	76.98	8.87	13.68	5.92	5.28
7.28	36.28	18.53	40.	21.55	15.74	9.94	9.81	11.66
8.91	9.16	9.72	10.08	6.62	13.04	16.88	5.51	7.09
13.11	4.6	3.9	4.36	4.21	4.43	4.33	3.87	12.38
.528	2.58	3.63	1.11	2.18	2.67	2.65	2.21	2.64
14.88	3.2	.424	.005	231.5	2.12	3.71	26.55	12.05
5.49	3.06	37.36	.472	1.77	4.	4.3	5.93	2.01
2.69	2.08	4.41	3.26	2.14	8.48	7.09	.334	1.41
.671	1.13	2.49	2.99	6.4	2.55	67.1	7.76	1.58
13.73	5.43	4.36	18.71	20.78	18.63	40.16	36.27	11.67
3.12	2.81	19.54	11.68	3.9	5.17	7.85	7.51	6.
22.47	8.04	1.79	.719	3.15	8.1	17.04	15.07	32.46
11.96	10.9	8.66	7.69	1.55	2.65	.566	.612	1.05
1.39	1.96	1.93	10.14	5.05	1.91	3.71	.65	.925
.576	.872	1.13	4.28	3.32	12.	4.09	6.57	1.14
1.69	1.08	.54	1.45	1.13	1.74	.916	1.4	3.32
.345	1.62	1.36	.186	.225	.513	.507	.649	1.94
2.62	8.36	.036	.001	1.42	.027	.15	.334	.285
.736	6.62	18.05	7.06	4.02	.006	376.8	2.28	3.08
6.639	6.489	5.849	2.172	22.492	6.118	-.187	.551	3.452
1.034	2.663	9.748	9.762	6.603	10.43	1.514	.225	-.608
-.651	1.369	-.135	.18	1.469	2.226	.501	11.945	18.241
-.985	-1.342	2.797	2.895	.622	.348	16.51	2.103	5.583
3.799	3.718	-.293	-.788	-.949	-.903	-.381	.061	.012
.131	.64	3.284	70.345	35.709	1.578	3.444	.501	.274
.274	13.735	5.454	15.62	6.767	4.283	1.981	1.932	2.644
1.593	1.686	1.898	2.034	.752	3.188	4.756	.356	.922
3.216	.037	-.204	-.046	-.097	-.021	-.056	-.214	2.926
-1.323	-.651	-.296	-1.135	-.784	-.621	-.628	-.774	-.631
.930	-.443	-1.358	-1.488	51.005	-.804	-.269	9.033	2.797
.348	-.49	14.278	-1.342	-.920	-.17	-.066	.504	-.841
101.02	74.98	110.58	14.24	77.	18.6	3.6	21.6	24.4
88.83	129.7	179.4	103.6	100.3	196.9	16.3	61.7	-6.8
16.1	33.3	8.2	16.3	79.	66.97	177.6	60.4	116.3
48.4	5.8	85.6	16.8	212.1	65.2	138.9	42.8	88.6
23.7	9.7	11.7	80.3	29.37	5.17	15.21	11.86	13.96
10.52	1.71	37.31	-2.90	-5.8	11.3	15.47	1.84	5.61
16.09	130.19	34.91	287.89	23.65	14.5	23.1	8.4	10.87
2.03	30.9	30.05	105.11	10.83	98.19	23.4	128.4	13.1
37.59	4.85	3.94	8.19	1.80	19.39	14.58	-12.6	-14.12
-13.	-20.6	36.75	9.51	8.21	9.03	5.98	5.22	5.34
59.49	-5.96	-3.0	-7.93	13.52	5.52	22.2	90.38	16.56
23.31	78.27	125.24	7.8	4.96	6.15	36.24	69.95	21.83

(4) TOTHRS is the total number of hours in each month.

(5) In the total yearly flow at each station, the years increase horizontally and there is a blank line between each station.

Next, the initial policy is printed out also under the general heading of system characteristics. If the MAX P4 option is on, each attempt to generate an initial policy is printed. Each attempt consists of increasing the value of ANPUMP (4) until a storage level in one of the reservoirs is below the minimum level needed to satisfy all demands up to P_4. When a failure occurs it is possible to compare the storage levels with the minimum levels required. Then ANPUMP (4) is slowly decreased until no failure occurs and this value of ANPUMP (4) is used to generate the initial feasible policy that will satisfy all demands.

During the generation of the initial policy, the <u>ending</u> storages of reservoirs 1 and 3 (STARS 1 (N + J) and STARS 3 (N + 1) and the minimum storage at the <u>end</u> of period N (S1 MIN (N + 1) and S3 MIN (N + 1)) are compared to test for feasibility. It is important to understand that for an arbitrary period N, STARS 1 (N) and STARS 3 (N) are the storage levels at the begining of period N and that STARS 1 (N + 1) and STARS 3 (N + 1) are the storage levels at the end of period N. This is the reason there is always one more storage level than the number of periods. For example, if there were 20 years in the study there would be 240 periods (months) but 241 storage levels required, since an initial and ending storage is needed for each period.

The program also prints out four intermediate variables in the initial policy. For the series configuration, these variables are as follows:

DELTAR - this is the additional release from storage by reservoir 3 (over and above what flows into reservoir 3) necessary to satisfy the downstream demand. Note that a positive value implies additional releases and a negative value implies possible storages.

OMEGA - this variable is the <u>total</u> downstream demand from reservoir 1, that is, if reservoir 1 releases OMEGA thousands of acre-feet all downstream demands will be satisfied.

E(N) - this is the total downstream demand just below reservoir 3.

VHEVA - the variable-head evaporation off reservoir 3.

For the parallel configuration these variables are:

DEMDR 1 - this is the demand on the releases of reservoir 1

VHEVAP - the variable-head evaporation off reservoir 3

The next thing printed by the program is the Annual firm energy table. This table is self-explanatory where DELTA 1 and DELTA 2 are the state increment increments. This table is followed by several pages of tables containing the storage levels of reservoirs 1 and 3 at the begining of each period for every iteration. As presented in these tables, the first iteration is the initial policy and the second iteration is the run with zero state increment increments. This is why the first two columns of these tables are the same.

If desalination is being considered, more tables are printed out showing the amount of desalinized water in thousands of acre-feet and the number of desalination units in operation for every period of every iteration. The monthly percentage breakdown of desalination unit utilization is also printed.

If the dump energy analysis flag is on, a table is printed showing the storages of both reservoirs at the end of each period as well as the firm and dump energy produced in each period. The last things printed out are:

(1) The annual dump energy produced each year and the average annual dump energy

(2) A table showing the mean monthly dump energy produced for each month (MMDE(J)), the maximum monthly dump energy produced for each month (MINDE(J))

(3) A table showing the present value of Annual dump energy at interest rate R (PVADE(R)) and the equivalent uniform Annual dump energy at interest rate R (EVADE (R))

A sample output from one of the runs is given below.

B. 2 Parallel Reservoir System

The program structure remains almost the same as for the series reservoir system and hence there are very few changes to be made in order to run the program. The changes necessary, and the new parameters used are described below.

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*** SYSTEM CHARACTERISTICS ***.

****

ENERGY CAPACITIES OF RESERVOIR 1

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	1.200	2.050	2.850	3.650	4.400	5.000	5.600	6.150	6.700	7.000	7.150	0.0	0.0
0.0	0.0	0.0	1.350	2.250	3.150	3.950	4.700	5.400	6.100	6.750	7.350	7.750	8.017	0.0	0.0
0.0	0.0	0.0	1.500	2.450	3.300	4.150	5.000	5.750	6.500	7.250	7.900	8.350	8.650	9.150	0.0
0.0	0.0	0.0	1.650	2.550	3.500	4.400	5.300	6.150	6.900	7.700	8.400	8.900	9.250	9.472	0.0
0.0	0.0	0.0	1.750	2.750	3.700	4.650	5.500	6.350	7.150	7.950	8.700	9.350	9.800	10.160	0.0
0.0	0.0	0.0	1.900	2.850	3.800	4.750	5.700	6.600	7.500	8.350	9.100	9.800	10.350	10.750	11.080
0.0	0.0	1.000	2.000	3.000	4.000	4.950	5.900	6.800	7.750	8.600	9.400	10.150	10.800	11.300	11.800
0.0	0.0	1.150	2.100	3.050	4.050	5.050	6.050	7.000	8.000	8.900	9.750	10.550	11.200	11.700	12.100
0.0	0.0	1.200	2.150	3.150	4.200	5.200	6.200	7.200	8.150	9.150	10.100	10.850	11.500	11.950	12.310
0.0	0.0	1.750	2.250	3.300	4.300	5.350	6.350	7.350	8.400	9.400	10.450	11.150	11.750	12.150	12.430
0.0	0.0	1.350	2.400	3.450	4.500	5.550	6.600	7.650	8.750	9.750	10.800	11.850	12.250	12.610	0.0
0.0	0.0	1.400	2.500	3.600	4.700	5.800	6.900	8.000	9.100	10.250	11.250	12.150	12.850	0.0	0.0
0.0	0.0	1.500	2.650	3.800	4.900	6.000	7.150	8.250	9.400	10.500	11.600	12.000	0.0	0.0	0.0
0.0	0.0	1.500	2.700	3.900	5.000	6.150	7.300	8.400	9.600	10.700	11.800	12.880	0.0	0.0	0.0
0.0	0.0	1.600	2.750	3.950	5.100	6.250	7.400	8.550	9.750	10.850	12.000	13.110	0.0	0.0	0.0
0.0	0.0	1.650	2.850	4.000	5.200	6.350	7.500	8.650	9.800	10.950	12.100	13.430	0.0	0.0	0.0
0.0	0.0	1.750	2.900	4.050	5.250	6.400	7.550	8.750	9.850	11.050	12.200	13.700	0.0	0.0	0.0

SYSTEM CHARACTERISTICS

ENERGY CAPACITIES OF RESERVOIR 3

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.100	4.750	5.400
5.950	6.400	6.850	7.300	7.750	8.375	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.200	4.950	5.700	6.450	7.150
7.850	8.550	9.200	9.900	10.550	11.250	11.900	12.400	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.150	5.050	5.850	6.700	7.550	8.400
9.200	10.000	10.900	11.700	12.500	13.300	13.950	14.450	14.840	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.600	5.550	6.500	7.450	8.400	9.300
10.250	11.200	12.150	13.050	13.900	14.700	15.450	16.150	16.600	16.930	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.950	6.000	7.000	8.000	9.000	10.100
11.100	12.100	13.100	14.100	15.100	16.050	16.900	17.650	18.250	18.750	19.040	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	4.200	5.300	9.400	7.500	8.600	9.750	10.850
11.950	12.950	14.000	15.100	16.150	17.150	18.050	18.900	19.600	20.250	20.750	22.610	0.0
0.0	0.0	0.0	0.0	0.0	0.0	4.500	5.650	6.750	7.900	9.050	10.250	11.350
12.500	13.600	14.700	15.900	17.000	18.000	19.050	20.000	21.000	21.650	22.150	22.700	23.450
0.0	0.0	0.0	0.0	0.0	0.0	4.650	5.800	7.000	8.200	9.400	10.600	11.800
13.000	14.150	15.350	16.550	17.750	18.900	19.950	20.850	21.750	22.550	23.250	23.800	24.300
0.0	0.0	0.0	0.0	0.0	0.0	4.900	6.000	7.100	8.200	9.500	10.700	12.000
13.200	14.450	15.700	16.950	18.150	19.450	20.500	21.450	22.400	23.200	23.750	24.250	24.580
0.0	0.0	0.0	0.0	0.0	4.000	5.050	6.250	7.400	8.650	9.900	11.150	12.450
13.650	14.950	16.200	17.500	18.700	19.900	21.100	22.200	23.200	24.000	24.550	25.220	0.0
0.0	0.0	0.0	0.0	0.0	4.850	5.950	7.200	8.450	9.650	10.900	12.100	13.350
14.550	15.850	17.200	18.450	19.750	20.950	22.100	23.250	24.250	25.250	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	5.000	6.250	7.450	8.650	9.950	11.250	12.400	13.650
14.900	16.300	17.550	18.900	20.200	21.450	22.750	23.800	25.060	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	5.150	6.450	7.700	9.000	10.300	11.550	12.750	13.950
15.250	16.700	18.050	19.400	20.700	21.950	23.250	24.400	25.600	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.000	5.250	6.550	7.850	9.100	10.500	11.750	13.000	14.350
15.650	17.100	18.500	19.850	21.200	22.550	23.900	25.140	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.050	5.300	6.650	7.950	9.250	10.650	11.900	13.200	14.650
15.950	17.400	18.850	20.200	21.600	23.000	24.300	25.700	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.100	5.400	6.750	8.100	9.400	10.750	12.050	13.350	14.850
16.150	17.600	19.050	20.450	21.900	23.350	24.750	26.000	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.150	5.450	6.650	8.200	9.500	10.850	12.200	13.500	14.900
16.300	17.750	19.200	20.700	22.150	23.600	25.070	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.350	5.700	7.150	8.550	9.700	10.350	12.700	14.100	15.500
16.650	18.450	19.800	21.250	22.550	24.100	25.430	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.400	5.800	7.350	8.850	9.950	10.650	13.050	14.500	15.900
17.050	19.000	20.300	21.650	23.000	24.600	25.490	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.450	5.900	7.300	8.700	10.100	11.700	13.150	14.600	16.000
17.300	19.050	20.400	21.800	23.200	24.750	25.750	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.750	5.950	7.450	8.900	10.350	11.800	13.250	14.750	16.200
17.650	19.150	20.600	22.050	23.500	25.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.550	6.050	7.550	8.950	10.500	11.900	13.450	15.000	16.450
16.950	19.500	20.950	22.300	23.850	25.130	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.600	6.100	7.650	9.000	10.650	12.000	13.650	15.150	16.550
17.150	19.750	21.250	22.550	23.150	26.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.650	6.150	7.750	9.250	10.750	12.300	13.800	15.300	16.850
18.350	19.900	21.350	22.800	24.350	25.790	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.750	6.250	7.800	9.300	10.850	12.400	13.900	15.400	16.950
18.500	20.500	21.550	23.000	24.450	26.280	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	4.800	6.300	7.850	9.350	10.900	12.450	13.950	15.500	17.050
18.600	20.100	21.650	23.150	24.700	26.700	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SYSTEM CHARACTERISTICS

					FLOW 1						
24.598	26.382	24.066	13.054	116.564	28.893	33.183	15.440	45.250	43.393	10.843	15.728
18.198	25.426	35.079	67.826	26.255	29.594	225.126	19.798	6.904	31.696	7.622	8.185
11.522	17.268	8.875	6.054	57.650	18.533	5.440	4.068	76.927	31.487	14.610	22.326
14.517	11.228	15.180	14.448	153.057	21.017	8.126	2.750	5.175	22.249	7.094	23.082
5.457	10.008	15.647	9.836	38.449	29.507	163.520	20.867	17.879	9.997	4.653	4.492
8.668	12.449	51.246	207.484	184.390	52.658	11.061	11.407	14.258	29.316	10.722	5.750
7.484	14.875	4.114	21.462	48.027	15.982	15.613	9.278	42.191	5.721	2.863	3.139
3.316	3.741	3.454	4.906	69.832	130.383	9.577	18.504	4.837	2.118	2.422	2.519
2.731	2.416	1.940	24.251	88.322	18.388	1.533	1.178	141.847	4.843	14.834	12.662
7.973	3.695	37.348	10.693	50.678	2.605	13.463	63.937	9.652	88.203	7.731	3.632
					FLOW 2						
21.260	20.920	19.450	10.440	53.010	20.070	3.950	6.060	13.700	9.120	7.400	11.710
28.080	28.110	21.180	29.520	8.700	5.140	2.710	2.670	2.580	8.310	4.100	5.010
8.580	10.580	5.920	32.660	45.050	8.440	1.570	0.469	12.050	12.300	6.260	5.490
41.730	10.260	18.830	10.270	14.560	14.360	3.640	2.170	1.680	1.820	3.390	4.670
4.530	7.140	4.870	6.310	13.280	182.000	76.980	8.870	13.680	5.920	5.280	5.610
7.280	36.280	18.530	40.000	21.550	15.740	9.940	9.810	11.660	10.390	8.910	9.160
9.720	10.380	6.620	13.040	16.880	5.510	7.090	3.470	13.110	4.600	3.900	4.360
4.210	4.430	4.330	3.870	12.380	5.330	0.528	2.580	3.630	1.110	2.180	2.670
2.650	2.210	2.640	21.770	14.890	3.200	0.424	0.005	231.500	2.120	3.710	26.550
12.050	6.610	5.490	3.060	37.360	0.472	1.770	4.000	4.300	5.930	7.010	2.190
					FLOW 3						
30.748	32.978	30.082	16.317	145.705	36.123	41.479	19.300	56.563	54.242	13.554	19.661
22.747	31.783	43.849	84.733	32.819	36.993	281.408	24.747	8.630	39.620	9.528	10.232
14.402	21.586	11.094	7.567	72.063	23.166	6.900	5.085	96.159	39.359	18.762	27.920
18.147	14.036	18.976	18.061	191.322	26.272	10.160	3.451	7.719	27.811	8.867	28.852
6.821	12.511	19.559	12.795	48.061	36.884	204.400	26.084	24.849	12.496	5.817	5.616
10.836	15.561	64.057	259.355	230.487	65.822	13.827	14.259	17.822	36.645	13.402	7.188
9.356	18.594	5.142	26.828	60.034	19.977	19.516	11.597	52.739	7.151	3.579	3.924
4.146	4.676	4.317	6.132	87.291	162.979	11.971	23.130	6.047	2.647	3.027	3.149
3.414	3.020	2.426	30.314	110.402	22.986	1.917	1.472	177.309	6.054	18.543	15.627
9.966	4.619	46.685	13.367	63.347	3.257	16.829	79.921	12.065	110.254	9.554	4.540
					FLOW 4						
6.639	6.489	5.849	2.172	22.492	6.118	-0.187	0.551	3.452	1.671	1.034	2.663
9.748	9.762	6.603	10.430	1.514	0.225	-0.608	-0.621	-0.651	1.369	-0.135	0.180
1.469	2.226	0.501	11.945	18.241	1.417	-0.085	-1.342	2.797	2.895	0.622	0.348
16.510	2.103	5.583	2.107	3.799	3.718	-0.293	-0.788	-0.949	-0.903	-0.381	0.061
0.012	0.940	0.131	0.640	3.284	70.345	35.709	1.578	3.444	0.501	0.274	0.391
0.274	13.735	5.454	15.620	6.767	4.283	1.981	1.932	2.644	2.153	1.593	1.686
1.898	2.034	0.752	3.188	4.756	0.356	0.922	-0.351	3.216	0.037	-0.204	-0.046
-0.097	-0.021	-0.056	-0.214	2.926	0.292	-1.323	-0.651	-0.296	-1.135	-0.784	-0.621
-0.628	-0.774	-0.631	6.864	3.930	-0.443	-1.358	-1.488	51.005	-0.804	-0.269	9.033
2.797	0.748	0.348	-0.490	14.278	-1.342	-0.920	-0.170	-0.066	0.504	-0.841	-0.781
					FLOW 5						
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SYSTEM CHARACTERISTICS

YEARLY DEMAND IN THOUSANDS OF ACRE FEET AT STATION 1 : 11.000

YEARLY DEMAND IN THOUSANDS OF ACRE FEET AT STATION 2 : 39.000

YEARLY DEMAND IN THOUSANDS OF ACRE FEET AT STATION 3 : 517.320

YEARLY DEMAND IN THOUSANDS OF ACRE FEET AT STATION 4 : 520.000

NUNITS	CAPDES	INTPOL	NYEARS	ITRTOT	MAXP4	ID	ISIM	THETA	RHO	MAXRHO	RHOINC
4	100.00	5	10	35	0	1	0	0.400	.600	0	.100

NUCLEAR CAPACITIES

187.000	140.000	94.000	47.000	0.0	0.0	0.0	0.0

AREAS OF RESERVOIR 1

2.860	4.980	6.850	8.530	9.890	11.310	12.600	13.760	14.790	15.820
16.730	17.630	18.400	19.050	19.820	20.470	21.110	21.750	22.470	23.370

AREAS OF RESERVOIR 3

1.820	3.120	4.250	5.380	6.300	7.100	7.880	8.650	9.320	10.100
10.620	11.300	12.020	12.700	13.300	13.980	14.590	15.250	15.980	16.600
17.250	18.000	18.650	19.250	20.000	20.600	21.250	21.950	22.550	23.150
23.820	24.480	25.150	25.800	26.450	27.100	27.780	28.400	29.100	29.700

CONSTANT HEAD AREAS : 6.375; 1.183

EVAPORATION RATES

0.030	0.020	0.160	0.070	0.130	0.470	0.740	0.730	0.360	0.400	0.270	0.100
0.030	0.020	0.160	0.070	0.130	0.470	0.740	0.730	0.360	0.400	0.270	0.100
0.030	0.020	0.160	0.070	0.130	0.470	0.740	0.730	0.360	0.400	0.270	0.100
0.030	0.020	0.160	0.070	0.130	0.470	0.740	0.730	0.360	0.400	0.270	0.100

EVAPORATION LOSSES IN THOUSANDS OF ACRE FEET

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.191	0.127	1.020	0.446	0.829	2.996	4.717	4.654	2.295	2.550	1.721	0.637
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.035	0.024	0.189	0.083	0.154	0.556	0.875	0.864	0.426	0.473	0.319	0.118

DS1	DR1	DS3	DR3	S1DEAD	S3DEAD
50.000	100.000	50.000	100.000	36.800	27.900

S1MAX,S3MAXA,S3MAXB,SINIT1,SINIT3,C5

992.475 ; 1165.000 ; 1350.000 ; 900.000 ; 1165.000 ; 0.0 ;

*RIMAXT

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
348.099	307.934	348.343	367.438	344.380	353.306	353.306	338.430	316.115	366.694	330.248	348.099
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
117.774	104.184	118.025	124.317	116.515	119.535	119.535	114.502	106.952	124.065	111.734	117.774

*DESCAP

2.378	2.148	2.378	2.302	2.378	2.302	2.378	2.378	2.302	2.378	2.302	2.378

*TOTHRS

744.000	672.000	744.000	720.000	744.000	720.000	744.000	744.000	720.000	744.000	720.000	744.000

**************** SYSTEM CHARACTERISTICS ****************

PUMPING DEMAND DISTRIBUTION

0.061	0.055	0.065	0.070	0.075	0.107	0.140	0.130	0.094	0.077	0.065	0.061
0.061	0.055	0.065	0.070	0.075	0.107	0.140	0.130	0.094	0.077	0.065	0.061
0.0	0.0	0.016	0.087	0.153	0.200	0.189	0.178	0.146	0.030	0.001	0.0
0.061	0.055	0.065	0.070	0.075	0.107	0.140	0.130	0.094	0.077	0.065	0.061

MONTHLY PUMPING DEMANDS

0.671	0.605	0.715	0.770	0.825	1.177	1.540	1.430	1.034	0.847	0.715	0.671
2.379	2.145	2.535	2.730	2.925	4.173	5.450	5.070	3.666	3.003	2.535	2.379
0.0	0.0	8.277	45.007	79.150	103.464	97.773	92.083	75.529	15.520	0.517	0.0
31.720	28.600	33.800	36.400	39.000	55.640	72.800	67.600	48.880	40.040	33.800	31.720

CONSTANT HEAD CAPACITIES :50.000;15.000

RMTCFS(2) = 9000.000 RMTCFS(4) = 3045.000

CONSTANT HEAD ENERGY RATES :71.000-;53.000

*TOTAL YEARLY FLOW AT EACH STATION

397.402	501.711	274.771	298.938	332.314	599.410	190.751	255.611	314.947	299.611
197.090	146.110	149.369	127.370	334.469	199.250	98.380	47.248	311.658	85.242
496.752	627.139	343.464	373.672	415.393	749.261	238.439	319.513	393.684	374.514
58.943	37.816	40.134	30.567	117.249	58.122	16.558	-1.980	64.437	14.065
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

AVERAGE MONTHLY INFLOW AT EACH STATION

10.447	12.749	19.695	38.002	83.322	34.757	48.665	16.724	36.792	26.902	8.340	10.153
14.009	13.662	10.786	17.094	23.765	26.026	10.860	4.010	30.789	6.152	4.713	7.742
13.058	15.936	24.619	47.502	104.153	43.446	60.831	20.905	45.990	33.628	10.425	12.691
3.862	3.724	2.453	5.226	8.199	8.497	3.294	-0.135	6.460	0.629	0.091	1.291
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

AVERAGE YEARLY INFLOW AT EACH STATION

346.546	169.617	433.181	43.590	0.0

FIRM ENERGY DISTRIBUTION

0.0660	0.0740	0.0780	0.0670	0.0660	0.1050	0.1330	0.1090	0.0810	0.0920	0.0710	0.0580

ON PEAK HOURS

468.	414.	469.	494.	463.	475.	475.	455.	425.	493.	444.	468.

R1MAXT: MAXIMUM TURBINE RELEASE RESERVOIR 1

0.0	0.0	0.0	1335.000	1375.000	1410.000	1445.000	1470.000	1515.000	1540.000
1550.000	1555.000	1530.000	1455.000	1350.000	1290.000	1265.000	1245.000	1230.000	1220.000

R3MAXT: MAXIMUM TURBINE RELEASE RESERVOIR 3

1750.000	1840.000	2060.000	2190.000	2290.000	2385.000	2470.000	2520.000	2530.000	2530.000
2430.000	2275.000	2195.000	2150.000	2085.000	2050.000	2020.000	1995.000	1965.000	1945.000
1925.000	1900.000	1890.000	1865.000	1845.000	1830.000	1815.000	0.0	0.0	0.0

STATE INCREMENT INCREMENTS :

0.0	100.000	50.000	25.000	10.000	5.000	1.000	1.000	1.000	1.000
0.0	100.000	50.000	25.000	10.000	5.000	1.000	1.000	1.000	1.000

************************ ANNUAL_FIRM_ENERGY ************************

ITERATION NUMBER	AFE (MWH/YEAR)	DELTA1 (1000 AF)	DELTA2 (1000 AF)	% ABOVE INITIAL POLICY	% IMPROVEMENT PER ITERATION
1	17249.434	0.0	0.0	0.0	0.0
2	17249.434	100.0	100.0	0.0	0.0
3	17250.027	50.0	50.0	0.003	0.003
4	17250.027	50.0	50.0	0.003	0.0
5	17250.105	25.0	25.0	0.004	0.000
6	17250.105	25.0	25.0	0.004	0.0
7	17264.129	10.0	10.0	0.085	0.081
8	17265.223	10.0	10.0	0.091	0.006
9	17266.316	10.0	10.0	0.098	0.006
10	17267.531	10.0	10.0	0.105	0.007
11	17268.836	10.0	10.0	0.112	0.008
12	20173.461	5.0	5.0	16.951	16.820
13	22723.652	5.0	5.0	31.736	12.641
14	22884.551	5.0	5.0	32.668	0.708
15	22982.793	5.0	5.0	33.238	0.429
16	22988.379	5.0	5.0	33.270	0.024
17	27768.449	1.0	1.0	60.982	20.793
18	39281.250	1.0	1.0	127.725	41.460
19	45715.578	1.0	1.0	165.026	16.380
20	49763.980	1.0	1.0	188.496	8.856
21	51851.359	1.0	1.0	200.597	4.195
22	52194.574	1.0	1.0	202.587	0.662
23	53662.875	1.0	1.0	211.099	2.813
24	54964.152	1.0	1.0	218.643	2.425
25	55058.754	1.0	1.0	219.192	0.172
26	55767.359	1.0	1.0	223.300	1.287
27	56418.734	1.0	1.0	227.076	1.168
28	57070.113	1.0	1.0	230.852	1.155
29	57686.234	1.0	1.0	234.424	1.080
30	57721.488	1.0	1.0	234.628	0.061
31	57798.266	1.0	1.0	235.073	0.133
32	57829.734	1.0	1.0	235.256	0.054
33	57861.148	1.0	1.0	235.438	0.054
34	58116.973	1.0	1.0	236.921	0.442
35	58141.410	1.0	1.0	237.063	0.042

*************** RESERVOIR 1 ***************

INITIAL STORAGE IN GIVEN PERIOD (1000 AF)

ITERATION NO. PERIOD	MONTH	1	2	3	4	5	6	7	8	9	10	11	12
1	1	900.000	900.000	900.000	950.000	950.000	975.000	975.000	985.000	985.000	985.000	985.000	985.000
2	2	923.940	923.940	923.940	923.940	923.940	948.940	973.940	983.940	983.940	983.940	983.940	983.940
3	3	949.877	949.877	949.877	899.877	949.877	949.877	949.877	959.877	959.877	959.877	959.877	959.877
4	4	970.146	970.146	970.146	920.146	970.146	945.146	970.146	960.146	960.146	960.146	960.146	960.146
5	5	956.514	956.514	956.514	906.514	906.514	881.514	906.514	896.514	896.514	896.514	896.514	896.514
6	6	989.496	989.496	989.496	989.496	989.496	989.496	989.496	989.496	989.496	989.496	989.496	989.496
7	7	954.254	954.254	954.254	904.254	954.254	979.254	979.254	989.254	989.254	989.254	989.254	989.254
8	8	891.622	891.622	891.622	841.622	791.622	816.622	841.622	831.622	831.622	841.622	851.622	861.622
9	9	819.817	819.817	819.817	769.817	719.817	719.817	694.817	684.817	674.817	684.817	694.817	704.817
10	10	813.958	813.958	813.958	763.958	713.958	688.958	663.958	653.958	653.958	653.958	663.958	673.958
11	11	830.228	830.228	830.228	780.228	730.228	705.228	680.228	670.228	670.228	680.228	690.228	700.228
12	12	825.439	825.439	825.439	775.439	725.439	700.439	675.439	665.439	675.439	685.439	695.439	705.439
13	1	836.157	836.157	736.157	736.157	696.157	686.157	661.157	671.157	681.157	691.157	701.157	711.157
14	2	853.723	853.723	753.723	753.723	703.723	703.723	678.723	688.723	698.723	708.723	718.723	728.723
15	3	878.723	878.723	778.723	778.723	728.723	728.723	703.723	713.723	723.723	733.723	743.723	753.723
16	4	910.330	910.330	810.330	760.330	760.330	735.330	735.330	745.330	755.330	765.330	775.330	765.330
17	5	970.577	970.577	870.577	820.577	820.577	795.577	795.577	805.577	815.577	825.577	835.577	845.577
18	6	951.575	951.575	851.575	801.575	801.575	801.575	801.575	801.575	811.575	821.575	831.575	841.575
19	7	902.450	902.450	802.450	752.450	702.450	677.450	677.450	687.450	697.450	707.450	717.450	727.450
20	8	975.874	975.874	975.874	925.874	875.874	875.874	875.874	885.874	895.874	895.874	895.874	885.874
21	9	904.188	904.188	904.188	854.188	854.188	854.188	854.188	864.188	864.188	864.188	874.188	874.188
22	10	848.589	848.589	848.589	848.589	848.589	823.589	823.589	823.589	823.589	823.589	823.589	813.589
23	11	852.206	852.206	852.206	852.206	852.206	827.206	827.206	827.206	827.206	827.206	827.206	817.206
24	12	840.832	840.832	840.832	840.832	840.832	815.832	815.832	805.832	795.832	805.832	805.832	795.832
25	1	837.296	837.296	837.296	837.296	837.296	812.296	812.296	802.296	792.296	792.296	792.296	782.296
26	2	842.582	842.582	842.582	842.582	842.582	817.582	817.582	807.582	797.582	797.582	787.582	777.582
27	3	857.271	857.271	857.271	857.271	857.271	832.271	832.271	822.271	812.271	802.271	792.271	782.271
28	4	849.061	849.061	849.061	849.061	849.061	824.061	824.061	814.061	804.061	794.061	794.061	784.061
29	5	850.762	850.762	850.762	850.762	850.762	825.762	825.762	815.762	805.762	795.762	785.762	775.762
30	6	899.668	899.668	899.668	899.668	899.668	874.668	849.668	839.668	829.668	819.668	809.668	799.668
31	7	843.141	843.141	843.141	793.141	793.141	768.141	743.141	733.141	723.141	713.141	703.141	693.141
32	8	751.617	751.617	751.617	701.617	701.617	676.617	676.617	666.617	656.617	646.617	636.617	626.617
33	9	664.310	664.310	664.310	664.310	664.310	639.310	639.310	629.310	619.310	609.310	599.310	599.310
34	10	689.177	689.177	689.177	689.177	689.177	689.177	689.177	679.177	669.177	659.177	669.177	669.177
35	11	697.438	697.438	697.438	697.438	697.438	697.438	697.438	687.438	677.438	677.438	687.438	697.438
36	12	695.769	695.769	695.769	695.769	695.769	695.769	695.769	685.769	685.769	685.769	695.769	695.769
37	1	707.053	707.053	707.053	707.053	707.053	707.053	707.053	697.053	697.053	697.053	707.053	707.053
38	2	720.993	720.993	720.993	720.993	720.993	720.993	720.993	710.993	710.993	710.993	720.993	720.993
39	3	729.355	729.355	729.355	729.355	729.355	729.355	729.355	719.355	709.355	709.355	719.355	719.355
40	4	740.610	740.610	740.610	740.610	740.610	740.610	740.610	730.610	720.610	710.610	720.610	720.610
41	5	728.421	728.421	728.421	728.421	728.421	728.421	728.421	718.421	708.421	698.421	688.421	678.421
42	6	842.395	842.395	842.395	842.395	842.395	817.395	817.395	807.395	797.395	787.395	777.395	767.395
43	7	794.591	794.591	794.591	744.591	744.591	719.591	694.591	684.591	674.591	664.591	654.591	644.591
44	8	708.269	708.269	708.269	658.269	608.269	583.269	558.269	548.269	538.269	528.269	518.269	508.269
45	9	621.791	621.791	621.791	571.791	521.791	496.791	471.791	461.791	451.791	441.791	431.791	421.791
46	10	565.974	565.974	565.974	515.974	515.974	490.974	465.974	455.974	445.974	435.974	425.974	415.974
47	11	555.328	555.328	555.328	505.328	505.328	480.328	455.328	445.328	435.328	425.328	415.328	405.328
48	12	543.877	543.877	543.877	493.877	493.877	468.877	443.877	433.877	423.877	413.877	403.877	393.877

************** RESERVOIR 3 **************

INITIAL STORAGE IN GIVEN PERIOD (1000 AF)

PERIOD	MONTH	25	26	27	28	29	30	31	32	33	34	35	36
1	1	1248.00	1248.00	1248.00	1248.00	1248.00	1248.00	1248.00	1248.00	1248.00	1248.00	1248.00	1248.00
2	2	1164.44	1164.44	1164.44	1164.44	1164.44	1164.44	1164.44	1164.44	1164.44	1164.44	1164.44	1164.44
3	3	1149.62	1149.62	1149.62	1149.62	1149.62	1149.62	1149.62	1149.62	1149.62	1149.62	1149.62	1149.62
4	4	1127.99	1126.99	1126.99	1126.99	1126.99	1126.99	1126.99	1126.99	1126.99	1126.99	1126.99	1126.99
5	5	1141.48	1140.48	1140.48	1140.48	1140.48	1140.48	1140.48	1140.48	1140.48	1140.48	1140.48	1140.48
6	6	1262.57	1262.57	1262.57	1262.57	1262.57	1262.57	1262.57	1262.57	1262.57	1262.57	1262.57	1262.57
7	7	1164.72	1164.72	1164.72	1164.72	1164.72	1164.72	1164.72	1164.72	1164.72	1164.72	1164.72	1164.72
8	8	1117.53	1117.53	1117.53	1117.53	1117.53	1117.53	1117.53	1117.53	1117.53	1117.53	1117.53	1118.53
9	9	1116.69	1117.69	1117.69	1117.69	1117.69	1117.69	1117.69	1117.69	1117.69	1117.69	1117.69	1118.69
10	10	1115.59	1115.59	1115.59	1115.59	1115.59	1115.59	1115.59	1115.59	1115.59	1115.59	1115.59	1115.59
11	11	1110.99	1110.99	1110.99	1110.99	1110.99	1110.99	1110.99	1110.99	1110.99	1110.99	1110.99	1110.99
12	12	1091.14	1091.14	1091.14	1091.14	1091.14	1091.14	1091.14	1091.14	1091.14	1091.14	1091.14	1091.14
13	1	1089.44	1089.44	1089.44	1089.44	1089.44	1089.44	1089.44	1089.44	1089.44	1089.44	1089.44	1089.44
14	2	1111.13	1111.13	1111.13	1111.13	1111.13	1111.13	1111.13	1111.13	1111.13	1111.13	1111.13	1111.13
15	3	1142.17	1142.17	1142.17	1142.17	1142.17	1142.17	1142.17	1142.17	1142.17	1142.17	1142.17	1142.17
16	4	1164.43	1164.43	1164.43	1164.43	1164.43	1164.43	1164.43	1164.43	1164.43	1164.43	1164.43	1164.43
17	5	1234.69	1235.69	1236.69	1237.69	1238.69	1239.69	1240.69	1241.69	1241.69	1241.69	1241.69	1241.69
18	6	1164.30	1164.30	1164.30	1164.30	1164.30	1164.30	1164.30	1164.30	1164.30	1164.30	1164.30	1164.30
19	7	1158.87	1158.87	1158.87	1158.87	1158.87	1158.87	1158.87	1158.87	1158.87	1158.87	1158.87	1158.87
20	8	1315.66	1315.66	1315.66	1315.66	1315.66	1315.66	1315.66	1315.66	1315.66	1315.66	1315.66	1315.66
21	9	1164.02	1164.02	1164.02	1164.02	1164.02	1164.02	1164.02	1164.02	1164.02	1164.02	1164.02	1164.02
22	10	1102.51	1103.51	1104.51	1105.51	1106.51	1107.51	1108.51	1109.51	1110.51	1111.51	1112.51	1113.51
23	11	1109.75	1108.75	1108.75	1108.75	1108.75	1108.75	1108.75	1108.75	1108.75	1108.75	1108.75	1109.75
24	12	1108.58	1109.58	1109.58	1109.58	1109.58	1109.58	1109.58	1109.58	1109.58	1109.58	1109.58	1110.58
25	1	1105.93	1106.93	1107.93	1108.93	1109.93	1110.93	1111.93	1112.93	1113.93	1114.93	1114.93	1115.93
26	2	1113.00	1112.00	1112.00	1112.00	1112.00	1112.00	1112.00	1112.00	1113.00	1114.00	1115.00	1116.00
27	3	1128.30	1129.30	1130.30	1131.30	1132.30	1132.30	1132.30	1132.30	1133.30	1134.30	1135.30	1136.30
28	4	1107.78	1108.78	1109.78	1110.78	1111.78	1112.78	1113.78	1114.78	1115.78	1116.78	1117.78	1118.78
29	5	1092.42	1092.42	1092.42	1093.42	1094.42	1095.42	1096.42	1097.42	1098.42	1099.42	1100.42	1101.42
30	6	1143.18	1142.18	1142.18	1143.18	1144.18	1145.18	1146.18	1147.18	1148.18	1149.18	1150.18	1151.18
31	7	1114.62	1115.62	1116.62	1115.62	1115.62	1115.62	1116.62	1117.62	1118.62	1119.62	1120.62	1121.62
32	8	988.68	989.68	990.68	991.68	992.68	993.68	994.68	995.68	994.68	995.68	996.68	997.68
33	9	847.62	848.62	849.62	850.62	851.62	852.62	853.62	854.62	855.62	856.62	857.62	858.62
34	10	834.33	835.33	836.33	837.33	838.33	839.33	840.33	841.33	842.33	843.33	844.33	845.33
35	11	826.96	827.96	828.96	829.96	830.96	831.96	832.96	833.96	833.96	833.96	833.96	834.96
36	12	813.02	814.02	815.02	816.02	817.02	818.02	819.02	820.02	821.02	822.02	823.02	824.02
37	1	828.49	828.49	828.49	828.49	828.49	828.49	828.49	828.49	828.49	828.49	829.49	828.49
38	2	846.20	846.20	846.20	846.20	846.20	846.20	846.20	846.20	846.20	846.20	846.20	846.20
39	3	859.88	859.88	859.88	859.88	858.88	857.88	856.88	855.88	854.88	853.88	852.88	853.88
40	4	864.69	863.69	862.69	861.69	860.69	859.69	858.69	857.69	856.69	855.69	854.69	855.69
41	5	880.15	879.15	878.15	877.15	876.15	875.15	874.15	873.15	872.15	871.15	870.15	871.15
42	6	1048.92	1049.92	1050.92	1051.92	1052.92	1053.92	1054.92	1055.92	1056.92	1057.92	1058.92	1059.92
43	7	1065.10	1066.10	1067.10	1068.10	1069.10	1070.10	1071.10	1072.10	1073.10	1074.10	1075.10	1076.10
44	8	1023.75	1024.75	1025.75	1026.75	1027.75	1028.75	1029.75	1030.75	1031.75	1032.75	1033.75	1034.75
45	9	932.09	933.09	934.09	935.09	936.09	937.09	938.09	939.09	940.09	941.09	942.09	943.09
46	10	815.06	816.06	817.06	818.06	819.06	820.06	821.06	822.06	823.06	824.06	825.06	826.06
47	11	801.12	802.12	803.12	804.12	805.12	806.12	807.12	808.12	809.12	810.12	811.12	812.12
48	12	781.36	782.36	783.36	784.36	785.36	786.36	787.36	788.36	789.36	790.36	791.36	792.36

AMOUNT OF DESALINIZED WATER
IN THOUSANDS OF ACRE FEET

ITERATION NO. PERIOD	MONTH	1	2	3	4	5	6	7	8	9	10	11	12
1	1	9.514	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2	8.593	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	3	9.514	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	4	9.207	9.207	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	5	9.514	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	6	9.207	9.207	9.207	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	7	9.514	9.514	9.514	9.514	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	8	9.514	9.514	9.514	9.514	9.514	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	9	9.207	9.207	9.207	9.207	9.207	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	10	9.514	9.514	9.514	9.514	9.514	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	11	9.207	9.207	9.207	9.207	9.207	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	12	9.514	9.514	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	1	9.514	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	2	8.593	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	3	9.514	9.514	9.514	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	4	9.207	9.207	9.207	9.207	9.207	9.207	9.207	0.0	0.0	0.0	0.0	0.0
17	5	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
18	6	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	0.0
19	7	9.514	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.514	9.514	9.514	9.514
20	8	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	0.0	0.0	0.0	0.0
21	9	9.207	9.207	9.207	9.207	9.207	9.207	9.207	0.0	0.0	0.0	0.0	0.0
22	10	9.514	9.514	9.514	9.514	9.514	9.514	9.514	0.0	0.0	0.0	0.0	0.0
23	11	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	0.0	0.0	0.0	0.0
24	12	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	0.0	0.0	0.0
25	1	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	0.0	0.0
26	2	8.593	8.593	8.593	8.593	8.593	8.593	8.593	0.0	0.0	0.0	0.0	0.0
27	3	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
28	4	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207
29	5	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
30	6	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207
31	7	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
32	8	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
33	9	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207
34	10	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
35	11	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207
36	12	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
37	1	9.514	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	2	8.593	8.593	8.593	8.593	8.593	8.593	8.593	0.0	0.0	0.0	0.0	0.0
39	3	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
40	4	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207
41	5	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
42	6	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207
43	7	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
44	8	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
45	9	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207
46	10	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514
47	11	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207	9.207
48	12	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514	9.514

NUMBER OF DESALINATION UNITS IN USE PER PERIOD

PERIOD	MONTH	1	2	3	4	5	6	7	8	9	10	11	12
		ITERATION NO.											
1	1	4	0	0	0	0	0	0	0	0	0	0	0
2	2	4	0	0	0	0	0	0	0	0	0	0	0
3	3	4	0	0	0	0	0	0	0	0	0	0	0
4	4	4	4	0	0	0	0	0	0	0	0	0	0
5	5	4	0	0	0	0	0	0	0	0	0	0	0
6	6	4	4	4	0	0	0	0	0	0	0	0	0
7	7	4	4	4	4	0	0	0	0	0	0	0	0
8	8	4	4	4	4	4	0	0	0	0	0	0	0
9	9	4	4	4	4	4	0	0	0	0	0	0	0
10	10	4	4	4	4	4	0	0	0	0	0	0	0
11	11	4	4	4	4	4	0	0	0	0	0	0	0
12	12	4	4	0	0	0	0	0	0	0	0	0	0
13	1	4	0	0	0	0	0	0	0	0	0	0	0
14	2	4	0	0	0	0	0	0	0	0	0	0	0
15	3	4	4	4	0	0	0	0	0	0	0	0	0
16	4	4	4	4	4	4	4	4	0	0	0	0	0
17	5	4	4	4	4	4	4	4	4	4	4	4	4
18	6	4	4	4	4	4	4	4	4	4	4	4	0
19	7	4	0	0	0	0	0	0	0	4	4	4	4
20	8	4	4	4	4	4	4	4	4	0	0	0	0
21	9	4	4	4	4	4	4	4	0	0	0	0	0
22	10	4	4	4	4	4	4	4	0	0	0	0	0
23	11	4	4	4	4	4	4	4	4	0	0	0	0
24.	12	4	4	4	4	4	4	4	4	4	0	0	0
25	1	4	4	4	4	4	4	4	4	4	4	0	0
26	2	4	4	4	4	4	4	4	0	0	0	0	0
27	3	4	4	4	4	4	4	4	4	4	4	4	4
28	4	4	4	4	4	4	4	4	4	4	4	4	4
29	5	4	4	4	4	4	4	4	4	4	4	4	4
30	6	4	4	4	4	4	4	4	4	4	4	4	4
31	7	4	4	4	4	4	4	4	4	4	4	4	4
32	8	4	4	4	4	4	4	4	4	4	4	4	4
33	9	4	4	4	4	4	4	4	4	4	4	4	4
34	10	4	4	4	4	4	4	4	4	4	4	4	4
35	11	4	4	4	4	4	4	4	4	4	4	4	4
36	12	4	4	4	4	4	4	4	4	4	4	4	4
37	1	4	0	0	0	0	0	0	0	0	0	0	0
38	2	4	4	4	4	4	4	4	0	0	0	0	0
39	3	4	4	4	4	4	4	4	4	4	4	4	4
40	4	4	4	4	4	4	4	4	4	4	4	4	4
41	5	4	4	4	4	4	4	4	4	4	4	4	4
42	6	4	4	4	4	4	4	4	4	4	4	4	4
43	7	4	4	4	4	4	4	4	4	4	4	4	4
44	8	4	4	4	4	4	4	4	4	4	4	4	4
45	9	4	4	4	4	4	4	4	4	4	4	4	4
46	10	4	4	4	4	4	4	4	4	4	4	4	4
47	11	4	4	4	4	4	4	4	4	4	4	4	4
48	12	4	4	4	4	4	4	4	4	4	4	4	4

```
30.0000 PERCENT OF MONTH NUMBER  1  HAVE 0 DESALINATION UNITS IN OPERATION
30.0000 PERCENT OF MONTH NUMBER  2  HAVE 0 DESALINATION UNITS IN OPERATION
20.0000 PERCENT OF MONTH NUMBER  3  HAVE 0 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  4  HAVE 0 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  5  HAVE 0 DESALINATION UNITS IN OPERATION
20.0000 PERCENT OF MONTH NUMBER  6  HAVE 0 DESALINATION UNITS IN OPERATION
20.0000 PERCENT OF MONTH NUMBER  7  HAVE 0 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  8  HAVE 0 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  9  HAVE 0 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER 10  HAVE 0 DESALINATION UNITS IN OPERATION
 0.0    PERCENT OF MONTH NUMBER 11  HAVE 0 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER 12  HAVE 0 DESALINATION UNITS IN OPERATION
--------------------------------------------------------------------------
 0.0    PERCENT OF MONTH NUMBER  1  HAVE 1 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  2  HAVE 1 DESALINATION UNITS IN OPERATION
 0.0    PERCENT OF MONTH NUMBER  3  HAVE 1 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  4  HAVE 1 DESALINATION UNITS IN OPERATION
 0.0    PERCENT OF MONTH NUMBER  5  HAVE 1 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  6  HAVE 1 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  7  HAVE 1 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  8  HAVE 1 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  9  HAVE 1 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER 10  HAVE 1 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER 11  HAVE 1 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER 12  HAVE 1 DESALINATION UNITS IN OPERATION
--------------------------------------------------------------------------
10.0000 PERCENT OF MONTH NUMBER  1  HAVE 2 DESALINATION UNITS IN OPERATION
 0.0    PERCENT OF MONTH NUMBER  2  HAVE 2 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  3  HAVE 2 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  4  HAVE 2 DESALINATION UNITS IN OPERATION
20.0000 PERCENT OF MONTH NUMBER  5  HAVE 2 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  6  HAVE 2 DESALINATION UNITS IN OPERATION
 0.0    PERCENT OF MONTH NUMBER  7  HAVE 2 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  8  HAVE 2 DESALINATION UNITS IN OPERATION
20.0000 PERCENT OF MONTH NUMBER  9  HAVE 2 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER 10  HAVE 2 DESALINATION UNITS IN OPERATION
20.0000 PERCENT OF MONTH NUMBER 11  HAVE 2 DESALINATION UNITS IN OPERATION
20.0000 PERCENT OF MONTH NUMBER 12  HAVE 2 DESALINATION UNITS IN OPERATION
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60.0000 PERCENT OF MONTH NUMBER  1  HAVE 3 DESALINATION UNITS IN OPERATION
60.0000 PERCENT OF MONTH NUMBER  2  HAVE 3 DESALINATION UNITS IN OPERATION
30.0000 PERCENT OF MONTH NUMBER  3  HAVE 3 DESALINATION UNITS IN OPERATION
 0.0    PERCENT OF MONTH NUMBER  4  HAVE 3 DESALINATION UNITS IN OPERATION
 0.0    PERCENT OF MONTH NUMBER  5  HAVE 3 DESALINATION UNITS IN OPERATION
 0.0    PERCENT OF MONTH NUMBER  6  HAVE 3 DESALINATION UNITS IN OPERATION
10.0000 PERCENT OF MONTH NUMBER  7  HAVE 3 DESALINATION UNITS IN OPERATION
 0.0    PERCENT OF MONTH NUMBER  8  HAVE 3 DESALINATION UNITS IN OPERATION
 0.0    PERCENT OF MONTH NUMBER  9  HAVE 3 DESALINATION UNITS IN OPERATION
20.0000 PERCENT OF MONTH NUMBER 10  HAVE 3 DESALINATION UNITS IN OPERATION
20.0000 PERCENT OF MONTH NUMBER 11  HAVE 3 DESALINATION UNITS IN OPERATION
40.0000 PERCENT OF MONTH NUMBER 12  HAVE 3 DESALINATION UNITS IN OPERATION
-----------------------------------------------------------------------------
 0.0    PERCENT OF MONTH NUMBER  1  HAVE 4 DESALINATION UNITS IN OPERATION
 0.0    PERCENT OF MONTH NUMBER  2  HAVE 4 DESALINATION UNITS IN OPERATION
40.0000 PERCENT OF MONTH NUMBER  3  HAVE 4 DESALINATION UNITS IN OPERATION
70.0000 PERCENT OF MONTH NUMBER  4  HAVE 4 DESALINATION UNITS IN OPERATION
70.0000 PERCENT OF MONTH NUMBER  5  HAVE 4 DESALINATION UNITS IN OPERATION
60.0000 PERCENT OF MONTH NUMBER  6  HAVE 4 DESALINATION UNITS IN OPERATION
60.0000 PERCENT OF MONTH NUMBER  7  HAVE 4 DESALINATION UNITS IN OPERATION
70.0000 PERCENT OF MONTH NUMBER  8  HAVE 4 DESALINATION UNITS IN OPERATION
60.0000 PERCENT OF MONTH NUMBER  9  HAVE 4 DESALINATION UNITS IN OPERATION
50.0000 PERCENT OF MONTH NUMBER 10  HAVE 4 DESALINATION UNITS IN OPERATION
50.0000 PERCENT OF MONTH NUMBER 11  HAVE 4 DESALINATION UNITS IN OPERATION
20.0000 PERCENT OF MONTH NUMBER 12  HAVE 4 DESALINATION UNITS IN OPERATION
-----------------------------------------------------------------------------
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DUMP ENERGY PRODUCTION

PERIOD	MONTH	S1 ENDING	S3 ENDING	DESALINATION UNITS	DESALINIZED WATER (1000 AF)	FIRM ENERGY	DUMP ENERGY
		992.000	1248.000				
1	1	991.940	1164.435	0	0.0	3837.332	165523.495
2	2	964.877	1149.623	0	0.0	4302.461	142816.239
3	3	965.146	1126.988	0	0.0	4535.027	149631.345
4	4	904.514	1140.476	0	0.0	3895.473	145333.660
5	5	991.496	1262.573	0	0.0	3837.332	148326.901
6	6	992.254	1164.722	0	0.0	6104.846	156932.259
7	7	879.622	1118.533	0	0.0	7732.805	164922.893
8	8	720.817	1118.694	0	0.0	6337.412	152957.557
9	9	698.958	1115.593	1	2.302	4709.453	118418.462
10	10	734.228	1110.986	0	0.0	5349.007	144622.147
11	11	739.439	1091.136	1	2.302	4128.039	102257.808
12	12	753.157	1089.435	1	2.378	3372.202	104804.385
13	1	770.723	1111.135	0	0.0	3837.332	137641.098
14	2	795.723	1142.168	0	0.0	4302.461	123729.562
15	3	827.330	1164.431	0	0.0	4535.027	138890.598
16	4	856.577	1241.689	1	2.302	3895.473	106447.776
17	5	879.575	1164.297	2	4.757	3837.332	89566.077
18	6	771.450	1158.870	1	2.302	6104.846	118648.530
19	7	909.874	1315.656	0	0.0	7732.805	167337.007
20	8	908.188	1164.021	1	2.378	6337.412	124430.804
21	9	834.589	1113.514	2	4.603	4709.453	87324.509
22	10	845.206	1109.747	2	4.757	5349.007	73465.826
23	11	819.832	1110.579	2	4.603	4128.039	68578.478
24	12	803.296	1115.931	2	4.757	3372.202	70698.309
25	1	807.582	1116.001	2	4.757	3837.332	67797.173
26	2	808.271	1136.302	1	2.148	4302.461	93124.105
27	3	804.061	1118.779	2	4.757	4535.027	71256.327
28	4	795.762	1101.475	2	4.603	3895.473	72319.380
29	5	815.668	1151.185	2	4.757	3837.332	79738.933
30	6	715.141	1121.615	2	4.603	6104.846	87026.569
31	7	643.617	997.676	1	2.378	7732.805	131019.000
32	8	599.310	858.617	2	4.757	6337.412	94014.979
33	9	661.177	845.328	2	4.603	4709.453	85448.439
34	10	683.438	834.957	1	2.378	5349.007	107648.116
35	11	689.769	824.023	2	4.603	4128.039	68198.637
36	12	707.053	828.489	2	4.757	3372.202	70458.354
37	1	720.993	846.203	0	0.0	3837.332	138939.336
38	2	724.355	853.078	3	6.445	4302.461	28912.347
39	3	735.610	855.689	3	7.135	4535.027	32640.873
40	4	686.421	871.145	4	9.207	3895.473	7654.929

Most of the modifications for the parallel case are accomplished within the program structure. In fact, the only data card affected by the change is the program control card. All the other parameters are unchanged.

The program control card for the parallel case will be:

MUNITS	columns (1-2), integer
CAPDES	columns (7-14), real
INTPOL	columns (15-17), integer
ISIM	columns (18-20), integer
ITRTOT	columns (21-23), integer
MAXP4	columns (24-26), integer
ID	columns (27-29), integer

These definitions are the same as for the series model.

THETA card columns (30-34), real

This variable is the fraction of the demand P_3 supplied by reservoir 1 and (1-THETA) of P_3 is supplied by reservoir 3 (see Figure 2).

RHO card columns (35-39), real

This variable is the fraction of the demand P_4 supplied by reservoir 1 and (1-RHO) of P_4 is supplied by reservoir 3.

MAXRHO card column (40-42), integer

This is an option flag for determining the maximum P_4 as a function of THETA and RHO as well as P_4. That is, if MAXRHO is on, THETA and RHO are both varied over 5 values incrementing up from the values read in with this program control card. The maximum P_4 the system can support is found for each of the 25 combinations of THETA and RHO and stored in an array called P4MAX (I,J). The largest P_4 in this array is found, the size of the increment by which THETA and RHO are incremented is divided in half, and a new P4MAX(I,J) is determined so that the largest P_4 from the old p4MAX(I,J) is centered in the new P4MAX(I,J). This same process is repeated one more time to determine the final ANPUMP(4) (that is, the largest P_4 the system can support), THETA and RHO to be used in generating the initial feasible policy. If MAXRHO is on, MAXP4 must be on also (both must equal 1). If MAXRHO is off (=0), MAXP4 can be either on or off. If MAXRHO is off and MAXP4 is on, the maximum P_4 that the system can support is found using only the values of THETA and RHO to generate the initial feasible policy. If both MAXRHO and MAXP4 are off, the values of THETA, RHO and ANPUMP(4) read into the program are used to simply generate the initial policy. Note that in this case if a failure occurs in the generation of the initial policy, the program terminates. Unless one of the variable head reservoirs is many times the size of the other, a good place to start THETA and RHO is .300.

RHOINC card columns (43-47), real

This variable is the increment by which THETA and RHO are increased when MAXRHO is on. When MAXRHO is off the value of RHOINC is arbitrary. Barring unusual circumstances, RHOINC is usually .100.

PRINTOUT FORMATS

The only real change in the printout formats is that if MAXRHO is on, the array containing the largest P_4 the system can support, P4MAX(I,J), is printed out under a system characteristics heading just before the initial policy. Finally, just before the dump energy analysis, the relative percentage of demand supplies by each of the parallel branches, R_2 and R_4, and desalinized water (if any) is printed out. A sample output for a parallel reservoir system is given below.

SYSTEM CHARACTERISTICS

ELEMENT 2,4 OF PAMAX(I,J) IS MAX ANPUMPT (4)

	RHO	0.300	0.400	0.500	0.600	0.700
THETA	.300	157.50	185.00	222.50	277.50	370.00
	.400	235.00	272.50	327.50	410.00	352.50
	.500	310.00	362.50	387.50	322.50	277.50
	.600	385.00	347.50	277.50	230.00	187.50
	.700	267.50	200.00	160.00	132.50	115.00

ELEMENT 3,3 OF PAMAX(I,J) IS MAX ANPUMP(4)

	RHO	0.500	0.550	0.600	0.650	0.700
THETA	.300	222.50	267.50	277.50	317.50	370.00
	.350	275.00	305.00	345.00	395.00	390.00
	.400	327.50	365.00	410.00	380.00	352.50
	.450	388.50	400.00	367.50	337.50	315.00
	.500	387.50	352.50	322.50	297.50	277.50

ELEMENT 3,3 OF PAMAX(I,J) IS MAX ANPUMP(4)

	RHO	0.550	0.575	0.600	0.625	0.650
THETA	.350	305.00	325.00	345.00	367.50	395.00
	.375	335.00	255.00	377.50	402.50	400.00
	.400	365.00	387.50	410.00	395.00	380.00
	.425	395.00	405.00	390.00	372.50	360.00
	.450	400.00	382.00	367.50	352.50	337.50

**************** *******
** SYSTEM CHARACTERISTICS **
****

ANPUMP(4) = 520.000 THETA = 0.400 RHO = 0.600

STARS1(N+1)	STARS3(N+1)	DEMOR1	VHEVA	DEMOR3	VHEVAP	S1MIN(N+1)	S3MIN(N+1)	N
923.940	1164.435	-7.074	0.658	4.658	0.565	36.800	27.900	1
949.877	1164.623	-8.183	0.446	3.682	0.377	36.800	27.900	2
970.146	1161.988	0.168	3.629	11.556	3.012	36.800	39.227	3
956.514	1138.476	25.095	1.591	38.522	1.306	36.800	27.900	4
989.496	1162.573	-2.004	2.978	39.371	2.427	67.232	120.993	5
954.254	1110.722	53.349	10.792	79.243	8.711	68.954	94.884	6
891.622	1048.533	79.389	16.427	90.501	13.167	58.217	69.232	7
819.317	971.694	71.709	15.536	83.857	12.272	36.800	27.900	8
813.958	960.593	43.644	7.464	61.826	5.838	36.800	27.900	9
830.228	984.986	18.801	8.322	23.327	6.521	36.800	27.900	10
825.439	982.136	9.299	5.633	11.968	4.434	36.800	27.900	11
836.157	991.435	2.922	2.088	8.717	1.645	36.800	27.900	12
853.723	1012.135	-13.894	0.631	1.549	0.499	36.800	27.900	13
878.723	1043.163	-15.373	0.426	0.409	0.339	36.800	27.900	14
910.330	1073.431	-1.562	3.472	10.802	2.783	36.800	27.900	15
970.577	1126.639	6.015	1.564	30.264	1.261	45.983	74.015	16
951.575	1096.297	42.306	2.950	60.849	2.361	47.624	57.489	17
902.450	1039.870	68.279	10.441	85.156	8.264	36.800	27.900	18
975.874	1151.656	80.629	16.601	90.922	13.343	84.045	169.410	19
904.188	1078.021	75.099	16.384	85.039	13.344	60.855	129.287	20
848.589	1014.514	54.764	7.739	65.929	6.207	36.800	86.674	21
852.206	1023.747	19.611	8.468	23.630	6.757	36.800	113.632	22
840.832	1015.579	13.299	5.698	13.137	4.559	36.800	118.921	23
837.296	1012.931	9.622	2.098	11.200	1.580	41.132	126.473	24
842.582	1017.001	5.606	0.630	9.828	0.504	52.654	139.814	25
857.271	1030.302	2.157	0.422	7.945	0.338	69.856	161.314	26
849.061	1021.779	13.698	3.388	16.904	2.713	78.113	164.494	27
850.762	999.425	2.875	1.478	28.749	1.172	83.875	153.877	28
899.668	1025.185	5.956	2.789	44.122	2.181	140.820	192.992	29
843.141	956.615	64.979	10.081	83.964	7.772	119.389	148.562	30
751.617	860.676	81.769	15.195	91.299	11.440	77.453	86.795	31
664.310	769.617	77.300	14.075	85.760	10.394	36.800	27.900	32
689.177	798.328	45.294	6.765	62.481	4.966	36.800	27.900	33
697.438	809.957	15.621	7.605	22.104	5.625	36.800	27.900	34
695.769	812.023	11.139	5.141	12.380	3.816	36.800	27.900	35
707.053	827.489	9.142	1.909	11.032	1.423	36.800	45.612	36
720.993	845.203	-27.544	0.578	-5.213	0.433	36.800	64.700	37
729.355	850.878	2.477	0.389	8.069	0.291	36.800	78.622	38
740.610	855.689	0.788	3.138	11.822	2.342	36.800	95.047	39
728.421	834.145	25.265	1.371	38.587	1.017	36.800	85.197	40
842.395	964.919	36.446	2.639	58.564	1.983	154.720	229.177	41
794.591	902.105	59.059	9.762	81.663	7.423	141.381	189.760	42
709.269	810.750	79.699	14.752	90.507	10.937	103.534	131.334	43
621.791	719.088	75.599	13.639	85.206	9.906	52.485	70.539	44
565.974	656.057	55.664	6.328	66.227	4.522	36.800	27.900	45
555.328	653.120	26.101	6.793	25.902	4.846	36.800	27.900	46
543.877	645.355	14.019	4.526	13.383	3.249	36.800	27.900	47
555.322	661.681	9.962	1.674	11.319	1.208	36.800	27.900	48
550.619	656.853	9.656	0.504	11.285	0.354	36.800	27.900	49
554.695	659.888	5.597	0.336	9.231	0.243	36.800	32.782	50
552.903	660.226	14.748	2.692	17.274	1.947	39.873	44.762	51
532.351	631.629	29.225	1.162	40.054	0.838	36.800	27.900	52
530.940	619.093	37.726	2.134	59.079	1.518	36.800	27.900	53
552.621	635.427	-108.581	7.826	15.036	5.514	36.800	27.900	54
696.381	775.732	6.359	13.402	54.605	9.490	49.980	84.166	55
634.705	709.290	68.899	13.644	82.840	9.686	36.800	49.016	56

PERIOD	STORAGES		RELEASES		PERC. OF DEMAND
1	992.000	991.940	R2 =	44.359	139.8453
	1248.000	1164.435	R4 =	117.957	371.8702
			DW =	0.0	0.0
2	991.940	964.877	R2 =	73.174	255.8520
	1164.435	1149.623	R4 =	51.735	180.8932
			DW =	0.0	0.0
3	964.877	965.146	R2 =	37.874	90.0102
	1149.623	1126.988	R4 =	52.883	125.6813
			DW =	0.0	0.0
4	965.146	904.514	R2 =	81.352	99.9326
	1126.988	1140.476	R4 =	0.897	1.1020
			DW =	0.0	0.0
5	904.514	991.496	R2 =	78.020	66.0351
	1140.476	1262.573	R4 =	40.516	34.2921
			DW =	0.0	0.0
6	991.496	992.254	R2 =	33.122	20.8180
	1262.573	1164.722	R4 =	126.219	79.3309
			DW =	0.0	0.0
7	992.254	879.622	R2 =	127.030	74.4725
	1164.722	1118.533	R4 =	67.425	39.5286
			DW =	0.0	0.0
8	879.622	720.817	R2 =	159.276	99.7453
	1118.533	1118.694	R4 =	0.440	0.2755
			DW =	0.0	0.0
9	720.817	698.958	R2 =	70.567	56.7220
	1118.694	1115.593	R4 =	52.464	42.1708
			DW =	2.302	1.8501
10	698.958	734.228	R2 =	6.124	11.0226
	1115.593	1110.986	R4 =	49.775	89.5877
			DW =	0.0	0.0
11	734.228	739.439	R2 =	5.299	15.4417
	1110.986	1091.136	R4 =	26.719	77.8578
			DW =	2.302	6.7070
12	739.439	753.157	R2 =	10.435	32.8987
	1091.136	1089.435	R4 =	19.742	62.2386
			DW =	2.378	7.4981
13	753.157	770.723	R2 =	27.250	85.9082
	1089.435	1111.135	R4 =	7.841	24.7202
			DW =	0.0	0.0
14	770.723	795.723	R2 =	27.399	95.8005
	1111.135	1142.168	R4 =	7.975	27.8861
			DW =	0.0	0.0
15	795.723	827.330	R2 =	19.619	46.6253
	1142.168	1164.431	R4 =	22.474	53.4116
			DW =	0.0	0.0
16	827.330	856.577	R2 =	65.413	80.3527

APPENDIX C
PROGRAM AVAILABILITY INFORMATION

A listing of the computer programs and/or FORTRAN card decks are available at cost from Econotech Systems, Post Office Box 2161, Seal Beach, California 90740, telephone (213) 474-3133. Instructions on the use of the programs can also be obtained from the same source.

The programs are exclusively written in FORTRAN, for easy compiling on any standard medium or large size computer. Binary decks suitable for operation on the IBM 360 series machines are also available, if desired.

APPENDIX D
DESALTING COST AND TRADEOFF POWER DATA

Tables D-1 to D-21 give the desalting and nuclear plant data obtained from the Oak Ridge National Laboratory, Oak Ridge, Tennessee. These data are used to calculate the desalting plant costs, a summary of which is given in Tables D-22 to D-26. The details of the calculation and an example are given in Section 4.3.

The process involved in deriving these cost figures is the VTE/MSF process (Vertical Tube Evaporation/Multi-Stage Flash). In this process the brine, after pretreatment is sent alternately through horizontal and vertical evaporative systems.

The dollar basis year for the cost figures is 1969. A 30-year plant life is presupposed, and an interest rate of 5 1/8% is assumed. The corresponding fixed charge rate is 6.6%.

TABLE D-1

Tradeoff Power (MW) for Four Module Plant Including Water Plant Power

Plant Size 100 MGD

Design Load Factor %	10	20	30	50	70	85
Evaporation Perform. Ratio	8.25	8.7	8.96	9.64	11.3	12.4
Production Ratio (MW/MGD)	2.4	2.25	2.18	2.02	1.72	1.57
Modules in Operation						
0	253	238	231	216	187	173
1	190	179	174	163	140	130
2	126	119	116	108	94	87
3	63	59	58	54	47	43
4	0	0	0	0	0	0

TABLE D-2

Tradeoff Power (MW) for Four Module Plant Including Water Plant Power

Plant Size 150 MGD

Design Load Factor %	10	20	30	50	70	85
Evaporation Perform. Ratio	8.25	8.7	8.96	9.64	11.3	12.4
Production Ratio (MW/MGD)	2.4	2.25	2.18	2.02	1.72	1.57
Modules in Operation						
0	379	357	347	323	281	260
1	284	267	260	242	211	195
2	190	179	174	162	140	130
3	95	89	87	81	71	65
4	0	0	0	0	0	0

TABLE D-3
Tradeoff Power (MW) for Four Module Plant Including Water Plant Power
Plant Size 200 MGD

Design Load Factor %	10	20	30	50	70	85
Evaporation Perform. Ratio	8.25	8.7	8.96	9.64	11.3	12.4
Production Ratio (MW/MGD)	2.4	2.25	2.18	2.02	1.72	1.57
Modules in Operation						
0	505	476	462	431	374	346
1	379	357	348	326	281	260
2	253	239	231	216	188	174
3	126	118	117	109	94	86
4	0	0	0	0	0	0

TABLE D-4
Tradeoff Power (MW) for Four Module Plant Including Water Plant Power
Plant Size 250 MGD

Design Load Factor %	10	20	30	50	70	85
Evaporation Perform. Ratio	8.25	8.7	8.96	9.64	11.3	12.4
Production Ratio (MW/MGD)	2.4	2.25	2.18	2.02	1.72	1.57
Modules in Operation						
0	632	592	578	539	468	433
1	474	446	434	405	351	324
2	316	297	288	270	234	216
3	158	149	144	135	117	108
4	0	0	0	0	0	0

TABLE D-5

Tradeoff Power (MW) for Four Module Plant Including Water Plant Power

Plant Size 300 MGD

Design Load Factor %	10	20	30	50	70	85
Evaporation Perform. Ratio	8.25	8.7	8.96	9.64	11.3	12.4
Production Ratio (MW/MGD)	2.4	2.25	2.18	2.20	1.72	1.57
Modules in Operation						
0	758	714	693	647	561	518
1	567	536	520	494	421	390
2	379	358	347	323	281	261
3	190	178	175	163	140	129
4	0	0	0	0	0	0

TABLE D-6

Unit Cost of Water from Dual-Purpose Desalting Plant as a Function of the Operating Plant Load and Optimum Load Factor

Plant Size 100 MGD

Operating Load Factor	Total Unit Water Cost ¢/1,000 gal. for the Plant that is Optimized at the given Plant Load Factor					
	10%	20%	30%	50%	70%	85%
10%	86.3	87.4	87.9	90.8	99.4	108.3
20%	52.6	52.6	52.8	53.8	57.6	61.8
30%	40.7	40.7	40.7	41.1	43.2	45.9
50%	31.5	31.3	31.2	31.2	32.0	33.2
70%	37.5	37.0	36.4	35.4	34.6	34.7
85%	35.7	35.2	34.6	33.5	32.5	32.3

TABLE D-7

Unit Cost of Water from Dual-Purpose Desalting Plant as a Function of the Operating Plant Load and Optimum Load Factor

Plant Size 150 MGD

Operating Load Factor	Total Unit Water Cost ¢/1,000 gal. for the Plant that is Optimized at the given Plant Load Factor					
	10%	20%	30%	50%	70%	85%
10%	83.3	84.1	85.3	88.5	96.6	104.7
20%	50.8	50.8	51.3	52.5	56.1	60.3
30%	39.6	39.6	39.6	40.3	42.2	44.4
50%	30.7	30.6	30.6	30.6	31.2	32.3
70%	36.8	36.3	35.7	34.9	34.1	34.1
85%	35.1	34.5	33.9	33.0	31.9	31.6

TABLE D-8

Unit Cost of Water from Dual-Purpose Desalting Plant as a Function of the Operating Plant Load and Optimum Load Factor

Plant Size 200 MGD

Operating Load Factor	Total Unit Water Cost ¢/1,000 gal. for the Plant that is Optimized at the given Plant Load Factor					
	10%	20%	30%	50%	70%	85%
10%	81.5	82.4	83.9	87.0	95.3	102.2
20%	49.9	49.9	50.5	51.7	55.4	58.8
30%	39.0	39.0	39.0	39.6	42.6	43.7
50%	30.2	30.2	30.2	30.2	30.9	31.9
70%	36.4	35.8	35.3	34.4	33.8	33.8
85%	34.7	34.1	33.6	32.6	31.7	31.2

TABLE D-9

Unit Cost of Water from Dual-Purpose Desalting Plant as a Function of the Operating Plant Load and Optimum Load Factor

Plant Size 250 MGD

Operating Load Factor	Total Unit Water Cost ¢/1,000 gal. for the Plant that is Optimized at the given Plant Load Factor					
	10%	20%	30%	50%	70%	85%
10%	80.0	81.3	82.4	85.4	93.8	101.5
20%	49.2	49.2	49.7	50.9	54.5	58.0
30%	38.5	38.5	38.5	39.0	41.0	43.1
50%	29.8	29.8	29.8	29.8	30.5	31.5
70%	36.1	35.5	35.0	34.1	33.4	33.4
85%	34.4	33.8	33.3	32.3	31.3	31.0

TABLE D-10

Unit Cost of Water from Dual-Purpose Desalting Plant as a Function of the Operating Plant Load and Optimum Load Factor

Plant Size 300 MGD

Operating Load Factor	Total Unit Water Cost ¢/1,000 gal. for the Plant that is Optimized at the given Plant Load Factor					
	10%	20%	30%	50%	70%	85%
10%	72.2	79.9	81.4	84.5	92.8	101.0
20%	48.5	48.5	49.1	50.4	53.9	57.7
30%	38.1	38.1	38.1	38.7	40.6	42.9
50%	29.6	29.6	29.6	29.6	30.2	31.3
70%	35.9	35.3	34.7	33.8	33.1	33.1
85%	34.2	33.6	33.0	32.0	31.1	30.8

TABLE D-11

Fixed Cost for Dual-Purpose Desalting Plants of a Conjunctive System

Plant Size 100 MGD

Design Load Factor	Unit Fixed Cost ¢/1,000 gal. for the Plant Operating at the following Plant Load Factors					
	10%	20%	30%	50%	70%	85%
10%	66.9	33.5	22.0	13.4	9.6	7.9
20%	68.5	34.3	22.8	13.7	9.8	8.1
30%	69.6	34.8	23.2	13.9	9.9	8.2
50%	72.7	36.4	24.2	14.5	10.4	8.6
70%	82.5	41.2	27.5	16.5	11.8	9.7
85%	92.0	46.0	30.7	18.4	13.1	10.8

TABLE D-12

Fixed Cost for Dual-Purpose Desalting Plants of a Conjunctive System

Plant Size 150 MGD

Design Load Factor	Unit fixed Cost ¢/1,000 gal. for the Plant Operating at the following Plant Load Factors					
	10%	20%	30%	50%	70%	85%
10%	64.3	32.1	21.4	12.9	9.2	7.6
20%	65.7	32.9	21.9	13.1	9.4	7.7
30%	67.1	33.6	22.4	13.4	9.6	7.9
50%	70.9	35.4	23.6	14.2	10.1	8.3
70%	80.2	40.1	26.7	16.03	11.45	9.4
85%	88.7	44.4	29.6	17.7	12.7	10.4

TABLE D-13

Fixed Cost for Dual-Purpose Desalting Plants of a Conjunctive System

Plant Size 200 MGD

Design Load Factor	Unit fixed Cost ¢/1,000 gal. for the Plant Operating at the following Plant Load Factors					
	10%	20%	30%	50%	70%	85%
10%	62.8	31.4	20.9	12.6	9.0	7.4
20%	64.2	32.1	21.4	12.8	9.2	7.6
30%	66.0	33.0	22.0	13.2	9.4	7.8
50%	69.6	34.8	23.2	13.9	9.9	8.2
70%	79.1	39.6	26.4	15.8	11.3	9.3
85%	87.1	43.5	29.1	17.4	12.4	10.2

TABLE D-14

Fixed Cost for Dual-Purpose Desalting Plants of a Conjunctive System

Plant Size 250 MGD

Design Load Factor	Unit fixed Cost ¢/1,000 gal. for the Plant Operating at the following Plant Load Factors					
	10%	20%	30%	50%	70%	85%
10%	61.5	30.7	20.5	12.3	8.78	7.2
20%	63.3	31.6	21.1	12.7	9.0	7.4
30%	64.7	33.4	21.6	13.0	9.3	7.6
50%	68.3	34.2	22.8	13.7	9.8	8.0
70%	77.9	38.9	26.0	15.6	11.1	9.2
85%	86.1	43.0	28.7	17.2	12.3	10.1

TABLE D-15

Fixed Cost for Dual-Purpose Desalting Plants of a Conjunctive System

Plant Size 300 MGD

Design Load Factor	Unit Fixed Cost ¢/1,000 gal. for the Plant Operating at the following Plant Load Factors					
	10%	20%	30%	50%	70%	85%
10%	60.9	30.4	20.3	12.2	8.7	7.2
20%	62.1	31.0	20.7	12.4	8.9	7.3
30%	63.9	31.9	21.3	12.8	9.1	7.5
50%	67.5	33.8	22.5	13.5	9.6	7.9
70%	77.0	38.5	25.7	15.4	11.0	9.1
85%	85.7	42.9	28.6	17.1	12.2	10.1

TABLE D-16

Unit Cost for Steam for Desalting Plants

Design Load Factor	PR	Steam Cost (¢/K gal.) for the following Operating Load Factors Based on Two Steam Costs, shown in the form High Cost (Low Cost) in the Table.					
		10%	20%	30%	50%	70%	85%
10%	8.25	20.7 (11.4)	20.7 (11.4)	20.7 (11.4)	20.7 (11.4)	20.7	20.7
20%	8.7	19.9 (10.8)	19.9 (10.8)	19.9 (10.8)	19.9 (10.8)	19.9	19.9
30%	8.96	19.1 (10.5)	19.1 (10.5)	19.1 (10.5)	19.1 (10.5)	19.1	19.1
50%	9.64	17.7 (9.8)	17.7 (9.8)	17.7 (9.8)	17.7 (9.8)	17.7	17.7
70%	11.3	15.1 (8.3)	15.1 (8.3)	15.1 (8.3)	15.1 (8.3)	15.1	15.1
85%	12.4	13.7 (7.6)	13.7 (7.6)	13.7 (7.6)	13.7 (7.6)	13.7	13.7

NOTE:

High cost or firm steam is available at all load factors. Low cost or interruptible steam is available only for load factors less than 70%. For the calculated cost in Tables D-22 and D-26, the low cost steam figure was used for these lower load factors.

TABLE D-17

Unit Cost (¢/1,000 gal.) for Fixed Charges of the Low Pressure Turbogenerator If Owned by Desalting Plant

Plant Size 100 MGD

Design Load Factor	10%	20%	30%	50%	70%	85%
LPTG Size - MW	253	238	231	216	187	173
Capital Cost 10^3\$	16,976	16,303	15,962	15,133	12,838	13,148
Desalting Plant Annual Load Factor						
10%	30.7	29.4	28.8	27.4	25.0	22.4
20%	15.4	14.8	14.4	13.7	12.5	11.2
30%	10.2	9.8	9.6	9.1	8.3	7.4
50%	6.2	5.9	5.7	5.5	5.0	4.5
70%	4.3	4.2	4.1	3.9	3.6	3.2
85%	3.8	3.7	3.6	3.4	3.1	2.8

TABLE D-18

Unit Cost (¢/1,000 gal.) for Fixed Charges of the Low Pressure Turbogenerator If Owned By Desalting Plant

Plant Size 150 MGD

Design Load Factor	10%	20%	30%	50%	70%	85%
LPTG Size - MW	379	357	347	323	281	260
Capital Cost 10^3\$	22,285	21,348	20,959	19,994	18,237	17,290
Desalting Plant Annual Load Factor						
10%	26.9	25.8	25.3	24.1	22.0	19.6
20%	13.5	12.9	12.6	12.1	11.0	9.8
30%	8.9	8.6	8.4	8.1	7.3	7.2
50%	5.4	5.1	5.0	4.9	4.4	3.9
70%	3.8	3.6	3.6	3.5	3.1	2.8
85%	3.4	3.2	3.1	3.0	2.9	2.5

TABLE D-19

Unit Cost (¢/1,000 gal.) for Fixed Charges of the Low Pressure Turbogenerator If Owned by Desalting Plant

Plant Size 200 MGD

Design Load Factor	10%	20%	30%	50%	70%	85%
LPTG Size - MW	505	476	462	431	374	346
Capital Cost 10^3\$	25,967	25,942	25,364	24,222	22,066	20,725
Desalting Plant Annual Load Factor						
10%	24.4	23.4	22.9	21.9	20.0	17.7
20%	12.2	11.7	11.5	10.9	10.0	8.8
30%	8.2	7.8	7.6	7.3	6.7	5.9
50%	4.9	4.7	4.6	4.3	4.0	3.5
70%	3.5	3.4	3.3	3.1	2.9	2.5
85%	3.0	3.0	2.9	2.8	2.5	2.2

TABLE D-20

Unit Cost (¢/1,000 gal.) for Fixed Charges of the Low Pressure Turbogenerator If Owned By Desalting Plant

Plant Size 250 MGD

Design Load Factor	10%	20%	30%	50%	70%	85%
LPTG Size - MW	632	592	578	539	468	433
Capital Cost 10^3\$	31,284	29,955	29,536	28,136	25,646	24,291
Desalting Plant Annual Load Factor						
10%	22.7	21.6	21.4	20.3	18.5	16.5
20%	11.3	10.9	10.7	10.2	9.3	8.3
30%	7.6	7.2	7.1	6.8	6.2	5.5
50%	4.5	4.3	4.3	4.1	3.7	3.3
70%	3.2	3.1	3.0	2.9	2.6	2.4
85%	2.9	2.7	2.7	2.5	2.3	2.1

TABLE D-21

Unit Cost (¢/1,000 gal.) for Fixed Charges of the Low Pressure Turbogenerator If Owned By Plant Size 300 MGD

Design Load Factor	10%	20%	30%	50%	70%	85%
LPTG Size - MW	758	714	693	647	561	518
Capital Cost 10^3\$	35,474	34,058	33,333	31,832	28,891	27,402
Desalting Plant Annual Load Factor						
10%	21.4	20.5	20.1	19.2	17.5	15.5
20%	10.7	10.2	10.1	9.6	8.7	7.8
30%	7.1	6.9	6.7	6.4	5.8	5.2
50%	4.3	4.1	4.0	3.8	3.4	3.1
70%	3.0	3.0	2.9	2.8	2.5	2.2
85%	2.7	2.5	2.5	2.4	2.2	2.0

TABLE D-22

Desalting Plant Costs

Plant Size 100 MGD

Unit Cost Category	Unit Costs in ¢/1,000 gal. for Plant Designed and Operated at the Same Load Factor 10%	20%	30%	50%	70%	85%	100%
Total Cost*	86.3	52.6	40.7	31.2	34.6	32.3	-
a. Fixed Cost	66.9	34.3	23.2	14.5	11.8	10.8	-
b. Variable Cost	19.4	18.3	17.5	16.7	22.8	21.5	-
(i) Steam Cost	11.4	10.8	10.5	9.8	15.1	13.7	12.5
(ii) OM & Mis. Var. Cost	8.0	7.5	7.0	6.9	7.7	7.8	-
Low Pressure Turbine Capital Cost 10^6\$	17.0	16.3	16.0	15.1	13.8	13.1	-

Annual Cost Category	Annual Costs in 10^6\$/Year for Plant Designed and Operated at the Same Load Factor 10%	20%	30%	50%	70%	85%
Fixed Cost	2.44	2.50	2.54	2.64	3.01	3.35
Steam Cost	4.56	4.56	4.56	4.56	4.56	4.56
OM & Misc. Cost	.29	.55	.77	1.26	1.97	2.42
Low Pressure Turbine Fixed Cost	1.12	1.07	1.05	1.00	.91	.86
Total Annual Cost	8.41	8.68	8.92	9.46	10.45	11.19

* Not including capital cost of low pressure turbine.

TABLE D-23

Desalting Plant Costs

Plant Size 150 MGD

Unit Cost Category	Unit Costs in ¢/1,000 gal. for Plant Designed and Operated at the Same Load Factor 10%	20%	30%	50%	70%	85%	100%
Total Cost*	83.3	50.8	39.6	30.6	34.1	31.6	-
a. Fixed Cost	64.3	32.9	22.4	14.2	11.5	10.4	-
b. Variable Cost	19.0	17.9	17.2	16.4	22.6	21.2	-
(i) Steam Cost	11.4	10.8	10.5	9.8	15.1	13.7	12.5
(ii) OM & Mis. Var. Cost	7.6	7.1	6.7	6.6	7.5	7.5	
Low Pressure Turbine Capital Cost 10^6\$	22.3	21.3	21.0	20.0	18.2	17.3	-

Annual Cost Category	Annual Costs in 10^6\$/Year for Plant Designed and Operated at the Same Load Factor 10%	20%	30%	50%	70%	85%
Fixed Cost	3.52	3.60	3.68	3.89	4.41	4.84
Steam Cost	6.84	6.84	6.84	6.84	6.84	6.84
OM & Misc. Cost	.42	.78	1.10	1.81	2.87	3.49
Low Pressure Turbine Fixed Cost	1.47	1.40	1.38	1.32	1.20	1.14
Total Annual Cost	12.27	12.62	13.00	13.86	15.32	16.31

* Not including capital cost of low pressure turbine.

TABLE D-24

Desalting Plant Costs

Plant Size 200 MGD

Unit Cost Category	Unit Costs in ¢/1,000 gal. for Plant Designed and Operated at the Same Load Factor 10%	20%	30%	50%	70%	85%	100%
Total Cost*	81.5	49.9	39.0	30.2	33.8	31.2	-
a. Fixed Cost	62.8	32.1	22.0	13.9	11.3	10.2	-
b. Variable Cost	18.7	17.8	17.0	16.3	22.5	21.0	-
(i) Steam Cost	11.4	10.8	10.5	9.8	15.11	13.7	12.5
(ii) OM & Mis. Var. Cost	7.3	7.0	6.5	6.5	7.4	7.3	-
Low Pressure Turbine Capital Cost 10^6\$	27.0	25.9	25.4	24.2	22.1	20.7	-

Annual Cost Category	Annual Costs in 10^6\$/Year for Plant Designed and Operated at the Same Load Factor 10%	20%	30%	50%	70%	85%
Fixed Cost	4.58	4.69	4.82	5.07	5.77	6.33
Steam Cost	9.12	9.12	9.12	9.12	9.12	9.12
OM & Misc. Cost	.53	1.02	1.42	2.37	3.78	4.53
Low Pressure Turbine Fixed Cost	1.78	1.71	1.67	1.59	1.46	1.36
Total Annual Cost	16.01	16.54	17.03	18.15	20.13	21.34

* Not including capital cost of low pressure turbine.

TABLE D-25

Desalting Plant Costs

Plant Size 250 MGD

Unit Cost Category	Unit Costs in ¢/1,000 gal. for Plant Designed and Operated at the Same Load Factor 10%	20%	30%	50%	70%	85%	100%
Total Cost*	80.0	49.2	38.5	29.8	33.4	31.0	-
a. Fixed Cost	61.5	31.6	21.6	13.7	11.1	10.1	-
b. Variable Cost	18.5	17.6	16.9	16.1	22.3	20.9	-
(i) Steam Cost	11.4	10.8	10.5	9.8	15.1	13.7	12.5
(ii) OM & Misc Var. Cost	7.1	7.8	6.4	6.3	7.2	7.2	
Low Pressure Turbine Fixed Capital Cost 10^6\$	31.3	30.0	39.5	28.1	25.6	24.3	

Annual Cost Category	Annual Costs in 10^6\$/Year for Plant Designed and Operated at the Same Load Factor 10%	20%	30%	50%	70%	85%
Fixed Cost	5.61	5.77	5.91	6.25	7.09	7.83
Steam Cost	11.40	11.40	11.40	11.40	11.40	11.40
OM & Misc. Cost	.65	1.42	1.75	2.87	4.60	5.58
Low Pressure Turbine Fixed Cost	2.06	1.98	1.94	1.85	1.69	1.60
Total Annual Cost	19.72	20.57	21.00	22.37	24.78	26.41

* Not including capital cost of low pressure turbine.

TABLE D-26

Desalting Plant Costs

Plant Size 300 MGD

Unit Cost Category	Unit Costs in ¢/1,000 gal. for Plant Designed and Operated at the Same Load Factor 10%	20%	30%	50%	70%	85%	100%
Total Cost*	79.2	48.5	38.1	29.6	33.1	30.8	-
a. Fixed Cost	60.9	31.0	21.3	13.5	11.0	10.1	-
b. Variable Cost	18.3	17.5	16.8	16.1	22.1	20.7	-
(i) Steam Cost	11.4	10.8	10.5	9.8	1.51	13.7	12.5
(ii) OM & Misc Var. Costs	6.9	7.7	6.3	6.3	7.0	7.0	
Low Pressure Turbine Fixed Capital Cost 10^6\$	35.5	34.1	33.3	31.8	38.9	37.4	-

Annual Cost Category	Annual Costs in 10^6\$/Year for Plant Designed and Operated in the Same Load Factor 10%	20%	30%	50%	70%	85%	100%
Fixed Cost	6.67	6.79	7.00	7.39	8.43	9.40	-
Steam Cost	13.68	13.68	13.68	13.68	13.68	13.68	13.68
OM & Misc. Cost	.76	1.69	2.07	3.45	5.37	6.51	-
Low Pressure Turbine Fixed Cost	2.34	2.25	2.19	2.10	1.90	1.81	-
Total Annual Cost	23.45	24.41	24.94	26.62	29.38	31.40	-

*Not including capital cost of low pressure turbine.

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